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LIGHTNING TO THE EMPIRE STATE BUILDING.

BY

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In recent years, much data have been obtained concerning the frequency of occurrence of strokes of lightning of different current magnitudes to electrical transmission lines through the use of the magnetic link [1] arranged to measure lightning currents flowing through the transmission tower. Lewis and Foust [2] found that in over 95 per cent. of the records obtained the tower top was positive with respect to the cloud.

That lightning strokes might be multiple in character has been known for many years, such strokes having been photographed through the use of moving cameras, in which the illumination of the stroke was drawn out along a time axis. The author showed in 1934,[3] using a crater lamp oscillograph,[4] that multiple strokes do occur to transmission lines, and therefore their characteristics should be determined in order that a complete picture of the problem of protection from lightning be obtained. The magnetic link, as used, has not been capable of giving any data concerning the multiple stroke.

In the problem of protection of electrical apparatus from lightning, not only should the magnitude of the current and frequency of occurrence be known, but, of equal importance, is a knowledge of possible wave shapes—how fast is the front in terms of amperes per microsecond, how slow can it be, and how long does the current persist. In the case of the multiple

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stroke, are the succeeding wave shapes like the first one, or how may they differ?

In general, the scheme of connecting a cathode ray oscillograph to a transmission line and measuring what arrives is not very satisfactory, chiefly because of the effect of the line on the wave due to travel and reflections, and furthermore, an unprotected line will flashover in the case of strokes of sufficient current magnitude, resulting in a modification of the wave in a manner usually unpredictable, since the point of flashover is frequently unknown. Although such studies have been undertaken,[5–6–7] they have been very expensive, and, in general, the results have been rather disappointing.

Norinder [8–9] used a somewhat different method of attack when he set up equipment for the purpose of determining the wave shape and magnitude of lightning discharges using a cathode ray oscillograph coupled to a vertical antenna. This method yielded interesting results, but is open to some objection from several points of view.

Schonland [10–11] and others [12–13–18–21] have been using the Boys camera in an effort to learn more about the mechanism of electrical discharges, both in nature and in the laboratory. The photographic method has been used by many different investigators with varying degrees of success, but Schonland and his associates have made the most comprehensive investigation to date. As a result of these photographic studies and according to the present conception, the lightning stroke is initiated by a so-called stepped leader beginning at the cloud and finding its way to the earth in a series of steps. If the stroke is to have branches, they are as a rule the result of the stepped leader dividing and progressing as two or more stepped leaders. When a stepped leader reaches the earth, the return stroke builds up from the earth toward the cloud through the path ionized by the stepped leader. At times, the return stroke fails to reach all the way from the earth to the cloud.

If the stroke is multiple, and other discharges occur to ground through substantially the same ionized path, they will be preceded usually by what has been termed a continuous leader, which begins at the cloud as did the stepped leader, but unlike the stepped leader it does not hesitate, but moves

toward the earth at an over-all velocity much higher than that of the stepped leader. As before, when contact is made with the earth, the return stroke builds up from the earth through the ionized channel. Generally, there will be no streamers associated with any but the first discharge of a multiple stroke.

With this background, McEachron and McMorris [14] have suggested that if lightning is about to strike a conducting mast on the earth's surface, the wave front of current flow through that mast takes place while the stepped or continuous leader is traversing the last two or three hundred feet of space just above the mast. Maximum current is reached when the downcoming leader makes contact with the top of the mast or streamer extending from the mast. The tail of the wave results from the flow of charges accumulated in the earth into the channel, uniting with those of opposite sign in and around the channel created by the leader. If this be true, one could produce an approximate oscillogram of the wave front of the stroke, providing the amount of charge and the velocity of propagation were known.

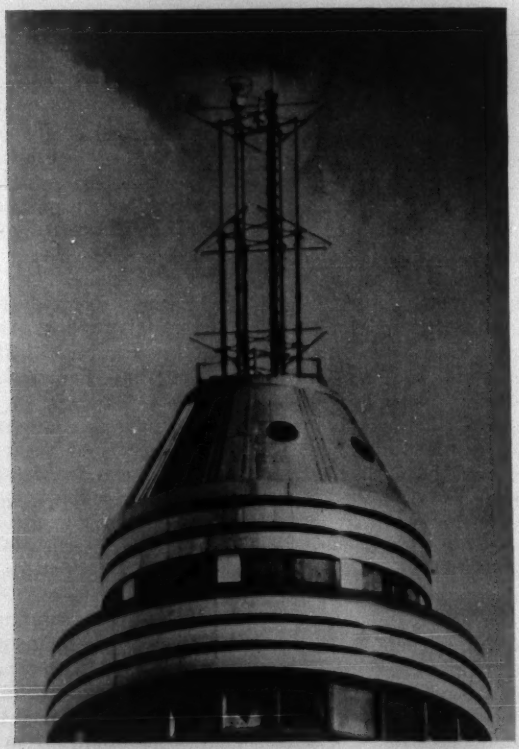
Perhaps the best method of approach to the problem of determining the mechanism of discharge and at the same time the possible wave shapes would be to photograph with Boys cameras the same stroke whose current time characteristics were being determined oscillographically.

During the summer of 1934, lightning stroke recorders (using Lichtenburg figures) had been associated with two experimental television antennas of the National Broadcasting Company on top of the Empire State Building, and it occurred to the author that here was the place to get oscillograms and photographs of the same stroke. Through the courtesy of the National Broadcasting Company, space was allotted for the installation of an automatic cathode ray oscillograph [15] in time for the 1935 lightning season. Late in the summer of 1936, a crater lamp oscillograph [15] was added to the installation. During the summers of 1935, 1936 and 1937, practically all of the strokes to the building after dark were photographed with a variety of types of Boys cameras. It is believed that new data of considerable interest have been obtained from the photographs, supported by crater lamp oscillograph data secured in 1937.

EMPIRE STATE BUILDING.

The Empire State Building in New York City is a steel frame building surmounted by a tower whose top is 1250 feet above the street. The top of the tower is constructed of metal, and extending above the top is an antenna system of the National Broadcasting Company, Fig. 1, which is used for

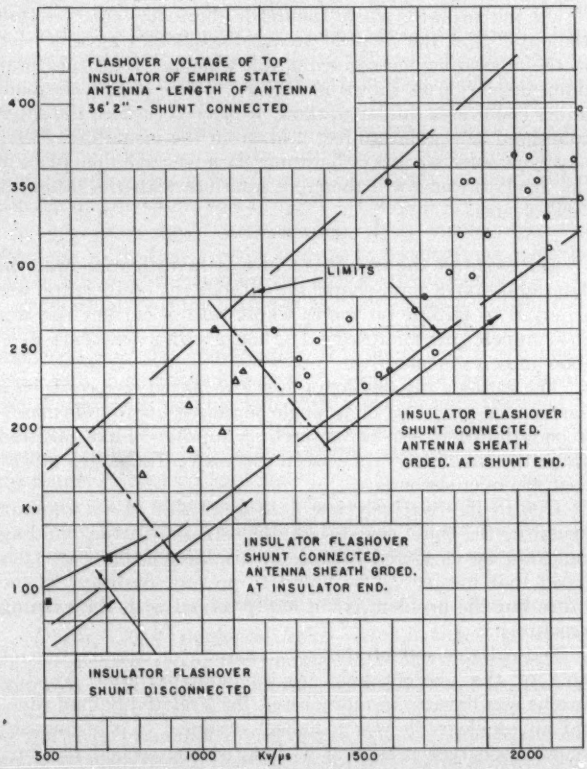
FIG. 1.



Antenna system atop Empire State Building. Completed in this form July 1936. G-E oscillographs connected to highest antenna (Photograph courtesy of Electronics). Dec. 16. 1937.

television experiments. Approximately in the center is an antenna which extends above the triangular system and terminates at a point 38 feet above the top of the building.

FIG. 2.



Insulator flashover data taken in the high-voltage laboratory at Pittsfield.

At a point 11.6 feet downward, the 1½ in. duraluminum rod enters a 5 inch (ID) brass pipe, being spaced from the pipe by suitable insulator.

During the taking of all of the oscillograms to be discussed in this paper, the inner conductor and outer pipe terminated at a point about 11.3 feet below the roof in a non-inductive shunt having a resistance of 0.03 ohm which is a part of the shunt used with the cathode ray and crater lamp oscillographs.

At the insulator where the inside conductor emerges from the outer pipe, the smallest arcing distance is 1.25 in. Tests in the laboratory have given a volt time curve for this minimum insulation as shown in Fig. 2. These tests were made under conditions similar to those in New York with the shunt connected at a point 36 feet 2 in. from the insulator. Obviously, for some strokes of lightning flashover will take place at the insulator, and will therefore interfere with the taking of oscillograms.

OSCILLOGRAPHS.*

Since one of the objectives of this investigation was the determination of wave shape, the cathode ray oscillograph was arranged to initiate on waves whose rate of current rise was 2000 amperes per microsecond or faster with a crest current of 6000 amperes or more.

The cathode ray oscillograph was designed to record, on a continuously moving film, single impulses up to 100 microseconds duration, also any succeeding impulses of like duration where the time interval between successive discharges was at least 500 microseconds.

Due to the relatively low flashover value of the antenna insulator, the most severe lightning strokes to the building could not be measured because of insulator flashover. It is hoped that means can be found to prevent flashover in the future but the problem is not easily solved with the existing structures.

Toward the end of the 1935 season, an examination of some of the photographic results indicated that possibly current was flowing, in many cases, for a relatively long time, and an oscillograph was installed, designed to continuously record discharges persisting as long as one second of time.

* It is expected that the instruments, including the cameras, practically all of which were specially designed for this investigation, will be described in detail in another paper by J. H. Hagenguth,[18] therefore only a brief discussion will be given here.

This oscillograph was an adaptation of the crater lamp oscillograph [4] used in the investigation at Roanoke, but some modifications were required since the oscillographs at the Empire State Building could only be serviced at the beginning or end of a storm. As used in New York, the crater lamp oscillograph galvanometer was connected to the shunt in the antenna circuit at all times, the drum carrying the SS-Pan film being run at constant speed, so that it was only necessary to supply the illumination for the optical system when a stroke occurred. This was done through the use of a crater lamp as a light source with a suitable initiating circuit, so that recording began within 20 microseconds after initiation voltage on the shunt was reached. The film speed was such that 0.90 inch equal 0.01 second. This oscillograph was arranged so that once set in motion 14 oscillograms could be taken without attention on the part of the operator.

The shunt used for both oscillographs consisted of the 0.03 ohm shunt, already mentioned, in parallel with a thyrite shunt. Using this combination of a linear and a non-linear resistance, currents as low as 20 amperes were indicated with the crater lamp oscillograph with a maximum measured of 24,000 amperes. The cathode ray oscillograph was set to record a minimum of approximately 1000 amperes, and a maximum of 200,000 amperes.

With both oscillographs, means were provided for determining the time of the stroke, so that the results could be correlated with those obtained from the various cameras.

MAGNETIC LINKS.

During 1935, magnetic links were arranged to record current flowing in the two vertical antennas which existed at that time. After the antenna shown in Fig. 1 was erected, the magnetic links were so placed that the current flowing in each of the seven grounded vertical pipes extending above the roof could be measured. Readings from these links would not be expected, unless the insulator at the top of the pipe to which the oscillograph shunts were connected flashed over, assuming of course that the stroke made contact at the highest point above the tower, which it did in every case that was observed,

save one,* during the three years of study. Although not every stroke was observed, data were obtained for the great majority. There is also a photograph by Gaty [16] which shows a discharge to a point some 60 ft. from the highest point, which at the time was the north antenna of the two antennas then in use. However, the number of strokes to the building for which current measurements could not be made was very small indeed. Furthermore, there is no evidence that any stroke divided, one part contacting some other part of the building, although one stroke (S-88) did first contact another much lower building, and later discharges in the same stroke made contact with the Empire State Building. Lacking evidence of subdivision, the currents measured can safely be assumed to be the total current in the stroke.

When considering magnetic link measurements, it must be remembered that the results represent the highest current [17] which passed, only in case all of the currents have been of the same polarity. If a reversal in polarity has taken place, either in the same discharge or between discharges, some measure of the reversal may be obtained if more than one link at different radial distances is used. In all of the Empire State installations, three links were used, giving a wider range of current values and helping to determine the true value when reversal took place.

PHOTOGRAPHIC EQUIPMENT.

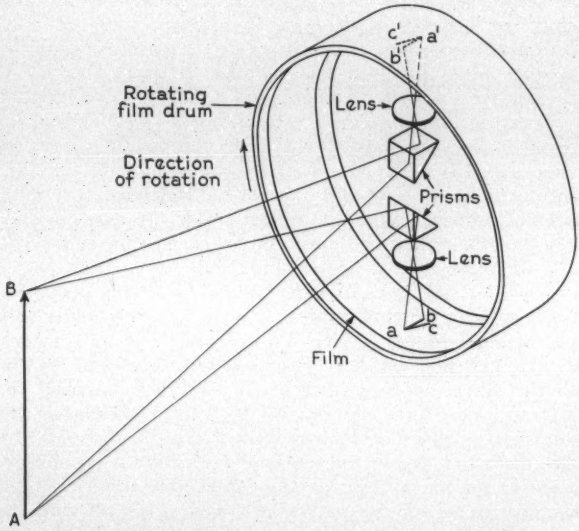
Naturally, during the three years that photographs have been taken, there has been considerable development of the various cameras used. No attempt will be made here to more than briefly describe these cameras and their development.

During the 1935 season, the cameras were located to the west of the Empire State Building in the Nelson Tower. A Boys camera (to which I have referred as a high speed Boys (HSB)), made by Ross in London, was loaned to us by Mr. A. L. Loomis of Tuxedo Park, and used by Lloyd and McMorris [18] to obtain the first photographs of leader strokes reported in this country. A schematic diagram showing the operation of

* This stroke observed in Aug. 1936 made contact about 16 ft. down from top of antenna.

this camera is given in Fig. 3, and shows how the use of two matched lenses and prisms allows a displacement of the image in opposite directions on the rotating film. A comparison of these two images, knowing the film speed, the focal length of

FIG. 3.



Schematic diagram of Boys camera with moving film and stationary optical system.

the lens, and the distance to the stroke, allows a determination to be made of the velocity of the continuous leaders and the return strokes. As a rule, the stepped leaders have a sufficiently slow overall velocity, so that a fair determination can be made without the second image. Of course comparison could be made with a still picture, but the resolution would not be as good.

This Boys camera was operated at a film speed of 145 feet per second. Since storm activity over the Empire State Building is usually rather brief, early in 1936 a new type of camera was designed and built in Pittsfield which would allow

seven exposures to be made while maintaining full film speed. This camera has the same optical system as that shown in Fig. 3. It was designed for film speeds up to 344 feet per second. During 1936 it was operated at approximately 218 feet per second, which was reduced for the 1937 season to 124 feet per second, since it was found that considerable data were being lost because of decrease in exposure time of weak portions of the stroke. To incorporate the feature of changing exposure while the film was running, it was necessary to operate with a short focal length, and 1.38 inches was adopted. A variety of different films was tried, but SS-Pan (chromatic) proved to be very satisfactory. For purposes of study, the image is greatly enlarged. With this camera are obtained the continuous leader data and most of the stepped leader data. Rates of propagation of the return stroke are also obtained from these so-called high speed Boys (HSB) camera records.

To determine the sequence of multiple stroke discharges, a slow speed (SSB) camera is necessary. For this purpose a camera was constructed using an 8 × 10 inch film holder with two matched lenses, having a focal length of 3.07 inches, mounted in front—one lens centering on the center of the film and the other revolving with a 2⅞ inch radius around the center lens as an axis. During the 1935 and 1936 seasons, the center lens revolved on its own optical axis, but because of a slight distortion due to the center of revolution being slightly different from the optical axis, this camera and another similar one constructed for the 1937 season were arranged with the center lens stationary. During 1935 and 1936, this camera was operated at one revolution per second, but when it was found that an occasional multiple stroke persisted for more than one second, it was decided to operate two similar cameras —one at two revolutions per second and the other at one-half revolution per second. The two center photographs, being taken with still matched lenses, could be put together to give a stereoscopic picture, since the cameras were on the same level and separated 14 inches.

Having two slow speed cameras has proved to be very helpful in analyzing the data, the slower of the two giving better overall data while the higher speed gives better resolution of individual discharges. Furthermore, having two

cameras of the rotating lens type makes it quite certain that for most strokes the image will be in a good position for resolution on one camera or the other. Of course the two cameras might have been operated at the same speed and mechanically coupled together with lens positions 90 degrees apart, which would have assured always getting the image in a good position for measurement on one film or the other, but this advantage was more than offset by the advantages resulting from the 4 : 1 speed ratio.

Other equipment was also provided to make the mechanical work of taking the records as simple and foolproof as could be easily done. A calculagraph was provided with which the time of operation and exposure of each camera was recorded in a manner similar to the timing of telephone toll messages. Each of the cameras had a printed form on which essential data, such as stop opening, kind of film, and other data pertinent to each camera were recorded. The time of day and elapsed time, using the calculagraph, were stamped on the same ticket.

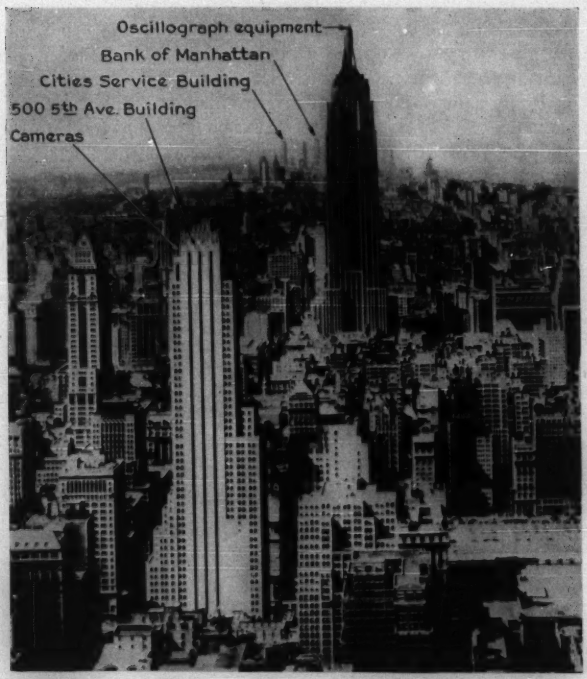
An ediphone was also provided for the recording of data, as the operator was often too busy to write down his observations. It was found, however, that the speaking tube restricted the operator too much as to freedom of motion, and in 1938 the operator will wear a lapel microphone, it only being necessary for him to change records, thus freeing him for other work. This method of recording was used during 1937 in the lightning investigation in progress in Pittsfield and proved to be quite satisfactory.

Based upon the sound of corona and the discharges from one's fingers when standing on the small balcony near the top of the Empire State Building when storms were several miles away, it was thought that a stroke to the building could be anticipated if streamers from the building could be seen during storms at night. A careful watch was kept, and during the 1937 season the top of the building was observed through a 35 power telescope, but as we later found out, the corona streamer built up into a stroke so fast that the eye could detect no time interval between them.

During the 1936 and 1937 seasons, space was made available, through the courtesy of Fletcher and Ellis, on the

56th floor of 500 5th Ave., which is a building located at the intersection of 42d St. and 5th Ave. This building, as seen in Fig. 4, is ideally located for studying lightning to the Empire

FIG. 4.



View from 70th floor of RCA Building, looking south toward 500 Fifth Avenue and Empire State Building (From photograph by E. Ratcliffe).

State Building. Not only is an excellent view obtained of the top of the Empire State Building, but the cameras are able to photograph a large number of strokes to lower Manhattan, which will be discussed in another paper. The map repro-

FIG. 5.

Field of view of cameras operated from 500 Fifth Avenue, New York City. Each concentric circle represents a distance of 5000 ft. from Empire State Building.

duced in Fig. 5 shows the section of New York covered by the cameras.

GENERAL CONSIDERATIONS.

It is realized that when making use of a tall structure, like the Empire State Building, the building acts as a great needle point, and may have a marked influence upon the character of the discharge. It was with this thought in mind that another investigation has been carried on concurrently in Pittsfield, Mass., in an observatory specially constructed for the purpose of studying lightning. Special camera equipment has been in operation since 1935, with the idea that comparisons between strokes to the Empire State Building, and strokes to the country-side around Pittsfield, would make a better application of the New York data possible when considering transmission lines and other structures of similar height. The detailed results of the Pittsfield study will be given in another paper, although some reference may be made to this work, and the conclusions given here will naturally be colored to some degree by the results obtained in Pittsfield.

During the progress of this lightning study, tests were also conducted in the High-voltage Engineering Laboratory at the Pittsfield Works of the General Electric Company, using Laboratory discharges. In so far as the data apply, they will be referred to in the appropriate place. These studies in the Laboratory have had to do largely with the effect of electrode shape and polarity on the direction of propagation, and the relation between current in a discharge and the photographic effects obtained.

It is recognized that the photographic method has limitations as a light measuring means, particularly from the quantitative point of view. However, on all photographs taken in the last two years, each film has a sensitometer calibration, so that densities may be compared using a microdensitometer. Such an instrument will, it is expected, soon be available for study of the records already made.

RESULTS.

During the three years of the investigation, the Empire State Building has been known to have been struck 68 times. Table I shows a summary of the strokes on which data were obtained.

TABLE I.

Summary of Strokes by Years.

Year.	Number of Storms.	Strokes to Building.	Oscillograms.		Photographs with			Number of Magnetic Link Records.
			Day.	Night.	HSB.	MSB.†	SSB*	
1935....	27	5	—	—	—	—	3	2
1936....	26	22	—	—	5	—	16	2
1937....	28	41	9	18	13	26	26	7

* 1 r.p.s. in 1935–6, ½ r.p.s. in 1937.
† 2 r.p.s. in 1937.

Nineteen oscillographic and photographic records were obtained simultaneously during 1937. No satisfactory records have been obtained with the cathode ray oscillograph up to the end of the 1937 season.

CONTINUING STROKES.

In 1935 three photographs were obtained of strokes to the Empire State and one of them also showed an interesting cloud to cloud stroke. Figure 6 shows a relatively weak initial stroke followed by an illumination which continued for 0.23 sec. Magnetic link readings indicated a negative current of 27,500 amperes. In Fig. 7 is a stroke to the building of quite different character, in that there were apparently several discharges followed by a period of varying but continuous illumination, with three rather considerable increases in intensity. These two photographs led the author to believe that the continuing illumination was not due to effects following the initial stroke, but represented a more or less continuous current flow. Apparently Walter [19] had the same idea in 1905, but there was no direct proof, and apparently little credence has been given to this idea since Walter's suggestion. It seemed incredible that the illumination could persist so long after the initial discharge unless current was flowing, and that at times the intensity could be even greater than the initial discharge, as illustrated in Fig. 7. From a study of these photographs, it was decided to install a crater lamp oscillograph and measure, over at least one second of time, any current which might be flowing, and since the

changes in current appeared for the most part to be rather slow, it was decided that the magnetic type oscillograph would be suitable.

Fig. 6.

Stroke to Empire State Building. Discharge taken with both still and rotating lens. June 27, 1935.

The results obtained in 1937, as illustrated by Fig. 8, show how beautifully the oscillograms and photographs check. The same oscillogram is reproduced in Fig. 9, being drawn to a

linear current scale. It will be noticed that each change in illumination is accompanied by a corresponding change in current. In general, where there is no illumination there is no

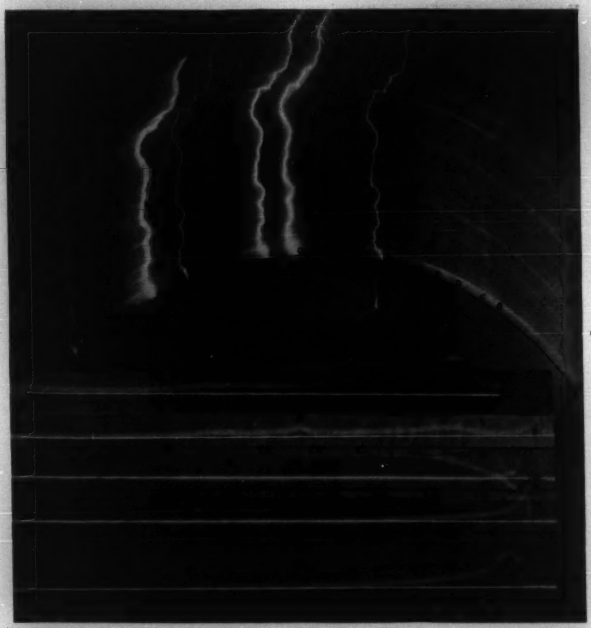
FIG. 7.

Stroke to Empire State Building and cloud to cloud discharges taken with both still and rotating lens. I. Stroke to Empire State Building. II and III. Cloud discharges. July 19, 1935.

current flow, but since the camera is 2410 feet away, a slight degree of illumination would not be recorded. Furthermore, the oscillograph could not detect currents of less than 20

amperes. Laboratory tests with a long time discharge, from a high current impulse generator, show that the illumination using the same Boys camera does persist as long as the current

FIG. 8.



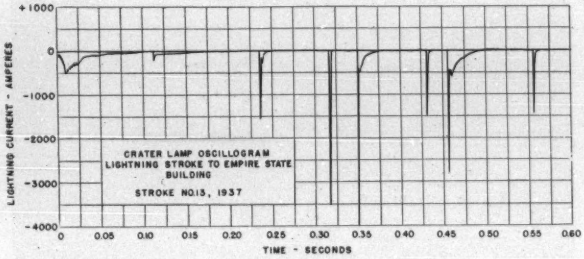
Multiple stroke to Empire State Building consisting of initial low-intensity long-continuing discharge and six subsequent discharges. The Boys camera photograph was obtained from 500 5th Avenue; oscillographic record below it was obtained in Empire State Tower. *A* to *K* mark corresponding points on photographic and oscillographic records. Stroke No. 13 of season.

flows, even for currents as small as 0.2 ampere. These tests, illustrated by Fig. 10, taken with oscillograph and camera, indicate that with the camera closer to the Empire State Building and the oscillograph set to record a smaller current,

longer times of current flow would undoubtedly have been found in some cases.

This type of stroke, in which the current flows for a relatively long period of time, has been termed a continuing

FIG. 9.



Replot of oscillogram of stroke No. 13 to Empire State Building. Aug. 11, 1937.

stroke. It may have superimposed upon it any number of current peaks.

When the current ceases entirely, for a period of 0.02 sec. or more, and a new discharge takes place through the same path, the stroke is referred to as being multiple. Of 47 strokes photographed on either or both the medium and slow speed cameras, 34 indicated continuous current flow until the end of the stroke, 4 consisted of two succeeding continuous discharges in the same path with a time interval between, while 7 others began as continuing strokes followed by distinct discharges. No strokes were found which could be called multiple strokes alone, without some of the continuing discharges mixed in. One stroke was observed consisting of a single discharge which was not continuing.

It is possible that all of the strokes would have been continuing if the equipment had been capable of detecting the effects of very small currents, although this does not seem likely based on present data.

These results indicate that the continuing discharge is really a direct current arc which may persist as long as 0.625

FIG. 10.

Photograph of discharge between electrodes spaced 1¼ in. using the SSB camera. Oscillogram taken simultaneously redrawn in polar coördinates.

sec. and may have superimposed current peaks of a variety of magnitudes.

DISCUSSION OF CONTINUING STROKES.

One might argue that the continuing type of stroke did not occur except to tall structures, yet once the discharge is started there seems to be little basis for assuming that the height of the building could have any great effect, except to

shorten the arc, thus requiring less potential to maintain it. There is no evidence of which the author is aware which indicates that sufficient potential would not be available to maintain an arc of the increased length required to reach the ground. The ground resistance of the building is very low, on account of the extensive foundations and pipe systems connected to its steel framework. If the cloud were a good conductor, there is no reason to believe that the discharge would be different from that of an impulse generator, to the degree that the discharge would obey the same laws, based on the R, L and C of the circuit. But the cloud is not a continuous conductor rather it consists of charges on drops of water separated by air gaps which must be broken down. Moreover, the cloud masses may be very large, and the charges in remote regions are not immediately available at the point of arc. The current peaks are perhaps the result of tapping new regions in the cloud which are separated or isolated by inhomogeneities of the cloud structure.

That the continuing type of discharge occurs to other than tall structures is evidenced by data from the Pittsfield observatory, which shows many of the discharges to be of this type. Because of the relatively rather great distance of some of the strokes from the camera, continuing illumination in some cases could not be photographed even if present.

One rather striking example of this type of discharge was photographed from Lake Maggiore in Switzerland, and is reproduced in Fig. 11. This interesting appearance was the result of the motion of the boat from which the photograph was taken, combined with a stroke which maintained almost constant intensity during its existence. Another similar photograph was taken in 1892 by W. N. Jennings from the rear of a train crossing a North Dakota prairie, and this is reproduced in Fig. 12. Many other photographs showing continuing strokes to other than tall conducting structures have been taken.

There is no doubt whatever in the mind of the author that continuing strokes are frequent to the open country, where the ground resistance may be either high or low, and that they also occur to transmission and distribution circuits where the ground resistance to direct current arc may be very low, as in

FIG. 11.

Continuing flash of lightning. Taken during last week in July 1937 on Lake Maggiore in Ascona, Switzerland. Supplied by Alice Gulda through Blue Hill Meteorological Observatory.

the case of the grounded neutral system, where the transformer winding represents a relatively small impedance to the flow of such unidirectional currents to ground.

Downward leaders, whether stepped or continuous, are

FIG. 12.

This photograph of so-called "Ribbon" lightning was taken in June 1892 from the rear platform of a sleeper on the North Dakota prairie by W. N. Jennings. The ribboning was due to the movement of the continuing path filled by subsequent discharges. Originally reproduced in *Electricity*, March 1893 (Chicago).

always followed by a return discharge building up from the ground end through the established channel. With the upward stepped leaders no return stroke, as such, is found—the last streamer having extended itself to meet either a down-

coming leader or streamer, current continues to flow in increased or decreased amount until the charges are so depleted that the discharge ceases. As a rule, the initial discharge of a continuing stroke is not very bright compared to discharges which may follow in the same path, but in eight cases the photographs gave the impression of a strong upward main stroke at the beginning, but close analysis, often in conjunction with other data available, indicated that the apparent brightness was in the upward streamers—more likely the result of a succession of closely packed bright streamer tips.

Schonland, Malan, and Collens [11] suggested that the return stroke process is dependent upon the availability of charge at the end of the leader channel, indicating that discharges into the air did not exhibit the return stroke process because of a lack of charges at the end of the streamer.

It would seem that the same explanation would account in part at least for the lack of return stroke process when a discharge proceeds from earth to cloud, i.e. sufficient cloud charge is not immediately available to produce the return stroke.

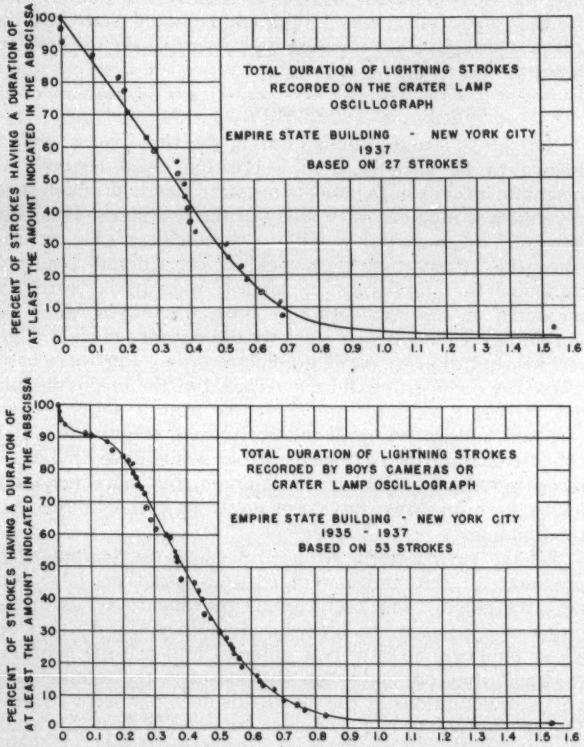
FULGURITES.

The author has tried on several occasions to produce fulgurites in the Laboratory, using discharges of various current magnitudes and time duration within the capabilities of the impulse generator available. Fulgurites could not be produced with the short time high current discharge, since the mechanical forces involved always blew the sand away. When, however, a discharge from a power source was used, with currents of relatively small amplitude—only a few amperes—fulgurites were easily obtained. This experience seems to indicate that fulgurites as found in nature are probably the result of long time low current continuing lightning discharges.

DURATION OF DISCHARGES IN THE SAME PATH.

The maximum duration of any stroke measured during the three years of study was 1.53 seconds, which is considerably longer than any reported heretofore. This time does not of course represent the longest duration which could occur, but

FIG. 13.


PERCENT OF STROKES HAVING A DURATION OF AT LEAST THE AMOUNT INDICATED IN THE ABSCISSA
TOTAL DURATION OF LIGHTNING STROKES
RECORDED ON THE CRATER LAMP
OSCILLOGRAPH
EMPIRE STATE BUILDING - NEW YORK CITY
1937
BASED ON 27 STROKES
0 10 20 30 40 50 60 70 80 90 100
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6
PERCENT OF STROKES HAVING A DURATION OF AT LEAST THE AMOUNT INDICATED IN THE ABSCISSA
TOTAL DURATION OF LIGHTNING STROKES
RECORDED BY BOYS CAMERAS OR
CRATER LAMP OSCILLOGRAPH
EMPIRE STATE BUILDING - NEW YORK CITY
1935 - 1937
BASED ON 53 STROKES
0 10 20 30 40 50 60 70 80 90 100
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6

Stroke duration as a function of the frequency of occurrence. Upper curve crater lamp oscillograph data only. Lower curve from both the oscillograph and the Boys cameras.

considering all the data of this and other investigations, it is probably close to the maximum. Using data from the crater lamp oscillograph alone, the upper curve in Fig. 13 was obtained. This shows that at least 50 per cent. of the discharges will have a duration of at least 0.35 second. The lower curve includes all of the data from both the oscillograph

and the Boys cameras, and shows slightly less than 0.4 sec. for the 50 per cent. point. It should be noted that the lower curve represents data covering 3 years, while the upper curve is for the year 1937 only.

POLARITY.

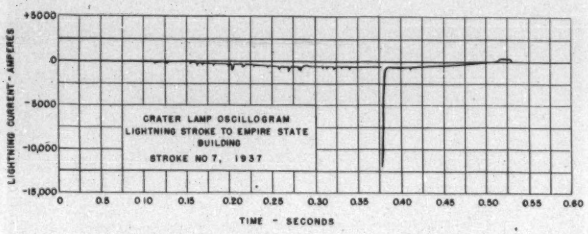
Of the 55 strokes studied during the three years, none is known to be initially from a positive cloud center. All magnetic link readings indicate negative cloud, although some reversal was obtained with many of the readings. It is best, however, to give most weight to the oscillographic records, since the information they yield is of a detailed nature, although the discharges of highest magnitude were not measured on the oscillograph. Those discharges which did not flashover the antenna insulator did not give magnetic link records, but did give oscillographic records. For those cases where the oscillograph did not record, but the magnetic links did, it is safe to state that no stroke from a positive cloud occurred, unless it were of relatively small magnitude. It is believed that during 1937 such a stroke would have produced a record on the crater lamp oscillograph, but since none was found there appears to have been no stroke initially positive to the building.

Of the twenty-seven strokes for which oscillograms were obtained all but three were entirely negative, i.e., from negative cloud. The oscillograms showing reversals in polarity of discharge are reproduced in Figs. 14, 17 and 19. These oscillograms show how different in detail the lightning discharge may be, and when one considers the infinite variations of conditions in the cloud this does not seem strange. The stroke (No. 7) of Fig. 14 was recorded in daylight, hence there is no Boys camera photograph for comparison. This record shows the maximum current recorded on the oscillograph to be − 13,000 amperes. The reversal came at the end of a long continuing stroke having many small peaks and the large one already mentioned. Throughout much of the stroke the current was of the order of 250 amperes. Reversal came at 0.51 sec., the positive current reaching a value of 250 amperes.

Figure 17 shows a continuing negative stroke (No. 14) of small magnitude, followed 0.064 sec. later by a negative

discharge having a crest of about 1500 amps. This was followed with almost exactly the same time interval by a positive discharge having a crest of about 2000 amps., and persisting for a little over 0.03 sec. The entire stroke had but few current peaks, but the reversal occurred at the end as with stroke No. 7 discussed in connection with Fig. 14.

FIG. 14.

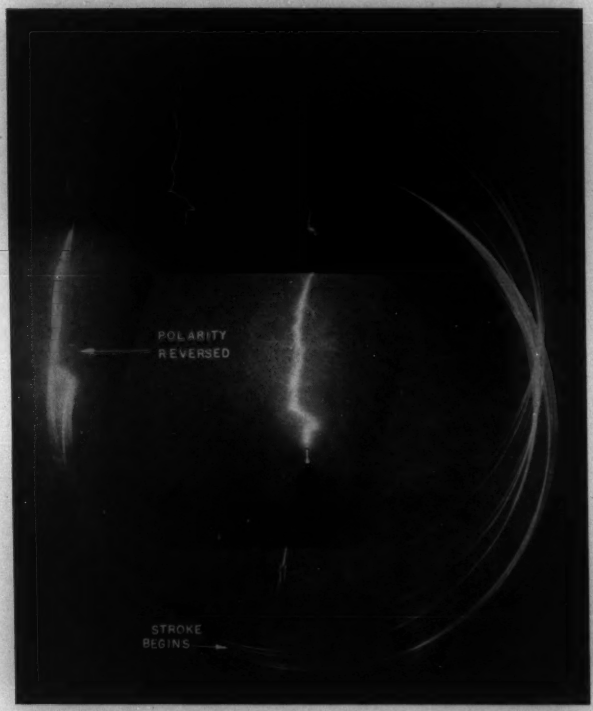


Redrawn crater lamp oscillogram showing maximum current of − 13,000 amps. with reversal at 0.51 sec. Total charge 164.1 coulombs of which 2.6 coulombs result from flow of positive current. This is the maximum charge measured.

Photographs were obtained of stroke 14 with all three cameras, the medium speed (2 r.p.s.) and the high speed (124 ft./s.) being reproduced in Figs. 15 and 16 respectively. Figure 15 shows the beginning of the stroke at the point marked, which by the way shows photographic reversal. The non-continuing discharge at 0.314 sec. had a downward continuous leader having a velocity of 9.5 ft./μs. (MSB). The position of the image of the third and final discharge which was positive was such as to make the determination of whether or not it possesses a leader rather difficult. At least none could be found in spite of the most careful examination of the original films. In no other regard was it possible to detect any difference which might be ascribed to change in polarity.

The HSB record shows two discharges which are known to be the last two discharges of the stroke, neither of which shows any leader although, as already stated, the slow speed camera shows that the negative discharge at 0.314 sec. did have a continuous leader. One of these is reproduced in Fig. 16. Since a downward leader did occur on the second

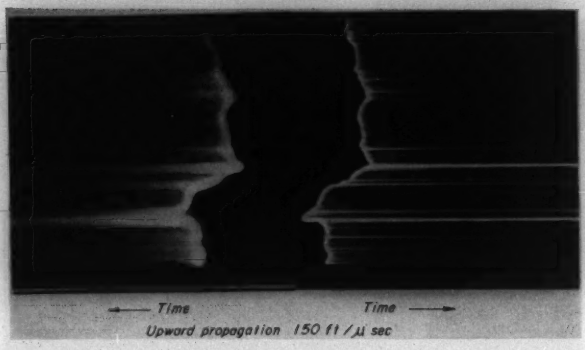
FIG. 15.



Multiple stroke consisting of initial long-continuing low-current discharge and two heavier discharges, last of which has positive polarity. Rotating lens image continued for more than one revolution. Stroke No. 14. Aug. 11, 1937.

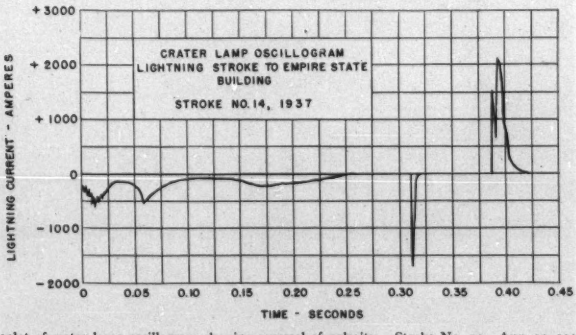
discharge, its absence on both of the high speed records proves nothing. It merely indicates that its intensity was not great enough to make a registration. The upward velocity of propagation of the return stroke as measured from the two images of the same discharge in Fig. 16 is 150 ft./μs. A similar measurement of the other discharge not reproduced also gives 150 ft./μs.

FIG. 16.



Single discharge of multiple stroke to the Empire State Tower taken with HSB camera. Stroke consisted of initial long-continuing low-current discharge and two heavier discharges, last of which is positive in polarity. It is not known of which of the last two discharges this is a photograph. Original negative shows no leader. Stroke No. 14. Aug. 11, 1937.

FIG. 17.



Replot of crater lamp oscillogram showing reversal of polarity. Stroke No. 14. Aug. 11, 1937.

The third case of reversed polarity is that of stroke No. 21, whose SSB (½ r.p.s.) record is shown in Fig. 18 with corresponding oscillogram in Fig. 19. As with the other two this stroke began as a continuing negative stroke, changing to positive at the end. The negative crest current was 600

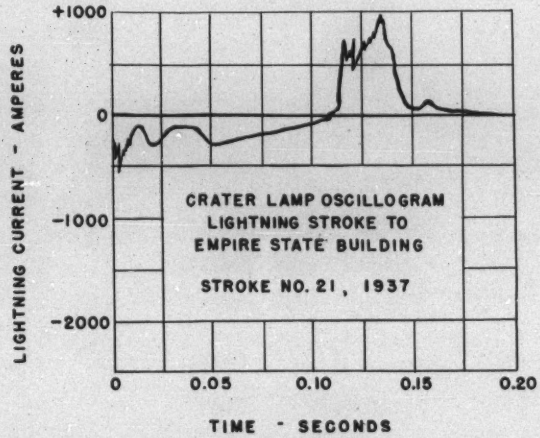
amperes, while the positive was a little over 900 amperes. Such a stroke would have registered as a positive stroke on a magnetic link. No leader stroke was found at the point of change of polarity, although the variations in current and the corresponding changes in intensity for approximately 0.01 sec. after reversal may have some significance. This will be discussed under the general heading of leader strokes.

Fig. 18.

Heavy single continuing discharge with large number of current peaks. Stroke reversed from negative to positive at 0.11 sec. Stroke No. 21. Aug. 12, 1937.

No distinguishing characteristics could be found from the SSB record which would identify this portion of the stroke as being positive. If the illumination died out when passing through zero current, it is not apparent on the film.

FIG. 19.

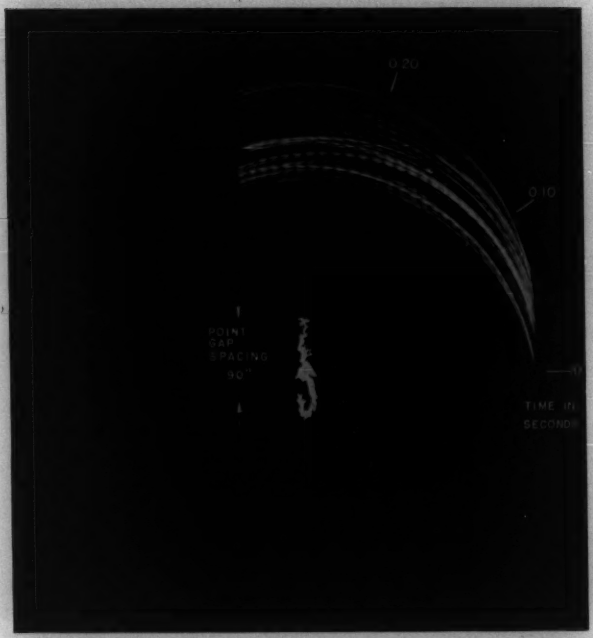


Replot of crater lamp oscillograph record showing reversal of polarity. Stroke No. 21. Aug. 12, 1937.

Laboratory tests on a vertical 60-cycle arc with a current of approximately 2 amperes flowing is shown in Fig. 20. Here the illumination in general dies out when the current passes through zero though many of the illumination streaks carry through. It should also be noted that the illumination is not continuous between the electrodes even though the current does flow continuously. This same phenomenon is apparent in the photograph of natural lightning with the moving lens in those cases where continuing strokes are being photographed.

Thus it appears that discharges to the building with positive cloud occur very rarely if ever. Approximately 90 per cent. of all discharges measured with the oscillograph were entirely negative. The other three strokes showing reversal began as continuing negative discharges, which seems to

FIG. 20.



SSB camera, 60 cy. arc. 2 amps. rms. center and rotating lens opened and closed simultaneously. Distance between electrodes approx. 90 in. (Arrows indicate vertical position of point gap, though displaced horizontally to avoid interfering with center lens photograph.)

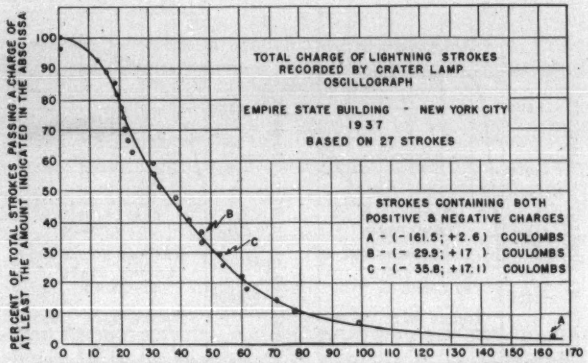
indicate that as the continuing discharge progressed, tapping more and more remote regions of the cloud, it finally reached an upper portion, perhaps where there was sufficient positive charges to give the results found.

AMOUNT OF CHARGE TRANSFERRED BY THE STROKE.

Until these oscillographic results had been analyzed, the author [14] believed, based on the best information available, that 20 coulombs were the maximum to be expected from a

single lightning stroke. However, stroke No. 7, whose oscillogram was given in Fig. 14 was found to have delivered a total charge of 164.1 coulombs, of which 2.6 coulombs results from the flow of positive current. 164 coulombs are about 8 times the maximum previously estimated. Figure 21 gives

FIG. 21.


PERCENT OF TOTAL STROKES PASSING A CHARGE OF AT LEAST THE AMOUNT INDICATED IN THE ABSCISSA
TOTAL CHARGE OF LIGHTNING STROKES RECORDED BY CRATER LAMP OSCILLOGRAPH
EMPIRE STATE BUILDING - NEW YORK CITY
1937
BASED ON 27 STROKES
STROKES CONTAINING BOTH POSITIVE & NEGATIVE CHARGES
A - (- 161.5; +2.6) COULOMBS
B - (- 29.9; +17) COULOMBS
C - (- 35.8; +17.1) COULOMBS
A
B
C
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170

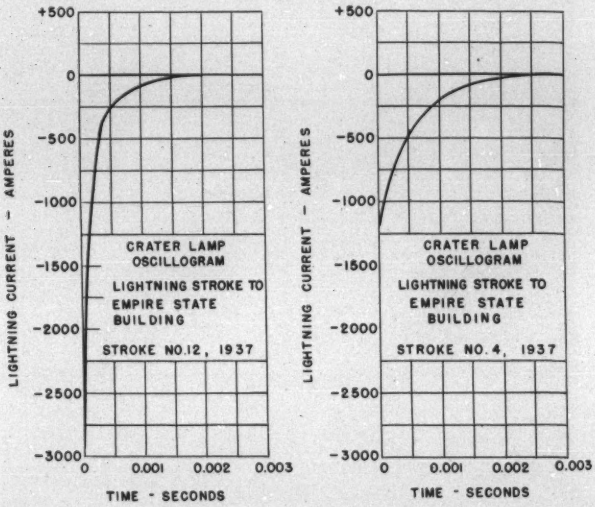
Frequency of occurrence of stroke charge of various magnitudes based on crater lamp oscillograph data for 27 strokes.

the results in curve form for all of the 27 strokes for which oscillograms are available. This curve indicates an expectancy of 35 coulombs or more in 50 per cent. of the cases.

The minimum charge probably means little, but to make the record complete, stroke 4 measured 0.67 coulombs and stroke 12 0.61 coulombs. Both of these were single negative discharges for which no photographic records are available. The values given for charge may be considered only as a close approximation, since the upper limit of registration of the oscillograph vibrator is about 5000 cycles. The front of each of these two records was too fast to record, and the crest current is no doubt somewhat in error. The two oscillograms are reproduced in Fig. 22. Stroke No. 4, having an indicated crest of 1200 amperes, reached half value in a little less than 0.0004 sec., while stroke No. 12 with a crest of 3000 amperes

decayed to half value in 0.0001 sec., while the oscillograph should be reasonably accurate up to 0.00005 sec. It is believed that the values given for charge for these two strokes are not seriously in error.

FIG. 22.



Replot of crater lamp oscillographic records showing Strokes 4 and 12 which were single negative strokes with no supporting camera data.

MECHANISM OF DISCHARGE.

One of the most important contributions which this investigation makes to the study of lightning as a natural phenomena is the discovery in 1936 and measurement of upward leaders * from the top of the building. As a matter of fact all of the continuing strokes on which it is possible to make a good analysis show the existence of the upward stepped leader. It is nearly always visible on the slow and medium speed camera photographs when the beginning of the stroke

* That upward leaders would be found was predicted by T. E. Allibone [22] in May 1938.

is so located upon the film as to make analysis possible. It is difficult to measure propagation velocities on these slower speed photographs, but over all velocities can be obtained in many cases.

The HSB camera has given some upward stepped leaders, the images being plain enough so that they should reproduce in a cut satisfactorily.

Seven strokes, which did not begin as continuing strokes and which had a steep enough rate of current rise to cause flashover of the antenna insulator, are all believed to have had downward initial leaders. Reliable data were obtained on 2 of these strokes.

There seems then to be two different types of strokes to the building, both negative in polarity—one being the case of the continuing relatively low current stroke beginning at the building and extending into the cloud, and the other being like that identified by Schonland where the stepped leader begins at the cloud. This type of stroke to the building *for the cases observed* is not initially continuing and has a high rate of current rise, and may reach a relatively high value of current before beginning to decay. Since downward and upward stepped leaders to the building, always with negative cloud polarity, have been observed, it would appear that the direction of propagation of the initial leader is not dependent upon polarity, but is dependent to a large degree upon the configuration of the two electrodes. Laboratory tests which will be discussed briefly later indicate that between needle and plane the discharge begins at the point irrespective of polarity, this has also been checked by Mathias and Allibone.[20, 22] Between two needles the discharge appears to start from each end, and this may be the case of the upward leader at the Empire State Building, but within the limit of our observation, which often extends as far as the stroke is visible, or at any rate 2600 feet vertically, no evidence has been found of a downcoming stepped leader to meet the one coming up from the building. An intermediate condition may exist with conducting structures with heights of the order of 100 feet as with transmission line structures.

It is quite certain that branching takes place in the direction of propagation, and is not dependent upon polarity.

This is confirmed by laboratory tests reported by Allibone and Meek [21] at reduced atmospheric pressure, as well as by unpublished work by the author. Allibone and Meek also found leaders from both electrodes when both were pointed. Most of the strokes to the Empire State Building which began with upward leaders do not show branching, but in five cases branching upward was found. In those cases where downward stepped leaders to the building were observed, no branching was found, although downward branching was found in cases where stepped leaders were not recorded. In no case was downward branching found with upward stepped leaders or vice versa.

It was of much interest to find that all of the subsequent discharges following the initial discharge were preceded by a continuous downward leader in every case where a leader of any sort was found. Frequently leaders could not be found for subsequent strokes, but they may have been too weak to photograph. The fact that they are found on so many subsequent strokes would strongly indicate that they could be found on all subsequent strokes through the same path, if the limitations of recording permitted. Once the path was established, whether by upward or downward stepped leader, subsequent leaders were always downward.

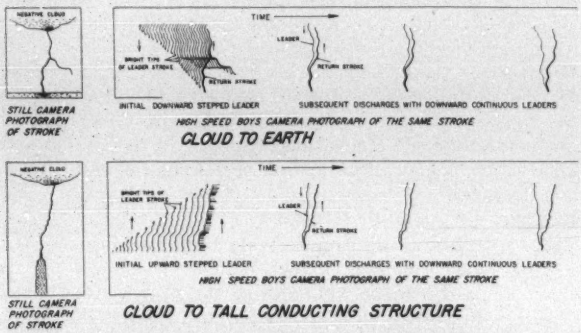
The current in a continuing stroke need not reach zero in order that a stroke may occur with a continuous downward leader. One example of this kind was found, the continuing current being something less than 20 amperes when the sudden increase in current appeared. In general, downward leaders are associated with high rates of current rise, while with upward initial leaders the rate of rise is relatively slow.

In Fig. 23 diagrammatic sketches show the usual type of leaders to be expected, comparing the case of the stroke to comparatively level earth to the stroke to a tall conducting object having a shape similar to that of the Empire State Building.

The author has been puzzled since first reading of the work of Dr. Schonland as to a method of attack which would allow one to measure the currents required to support the stepped leaders when fed from the cloud. When the streamers are upward and are fed from the antenna through our oscillograph

shunt, the problem of measurement becomes much easier. Since the time interval between the steps as measured by the HSB camera is of the order of 20 microseconds, only a cathode ray oscillograph would correctly measure these streamer

FIG. 23.



Schematic diagram showing discharges from negative cloud to substantially flat terrain and discharges from negative cloud to tall structures such as Empire State Building. In a small number of cases the downward step leader type has been observed to the Empire State Building.

currents. Such equipment will be installed for the 1938 season. However, the oscillograms do show a period of fluctuation during the streamer period which corresponds to a similar fluctuation in illumination at the beginning of the continuing stroke. This type of disturbance is plainly visible in Figs. 7, 25 and 32.

The first streamer currents are not recorded on the crater lamp oscillograph, but if the period of fluctuation of illumination at the beginning of the continuing stroke indicates streamer currents feeding leaders within the cloud or out of range of the cameras, then the data we have indicates that these currents may be of the general order of 50 to 650 amperes. The first few streamers, those feeding the portion of the leader within the range of the cameras, appear to vary from 50 to 200 amperes.

Considerable interest centers around what happens with a change in polarity, but no distinguishing difference could be found. However, when looking at the stroke shown in Fig. 18

which began with an upward stepped leader, with cloud negative, and changed to positive, one would expect to find an upward stepped leader where the polarity reversed, based on the appearance of this positive discharge. Although it is true that the characteristic rapid changes in intensity are present as with the upward stepped leader, all of the streamers reach out of the range of the photograph, indicating that they are probably feeding a stepped leader reaching into a positive portion of the cloud. The oscillogram shows also the characteristic disturbance of the upward stepped leader, but rises to a higher average current value, possibly indicating the presence of a stepped leader into a new cloud region. In connection with Fig. 15 there is also an indication of a second stepped leader when the polarity reversed.

LEADERS.

Of 17 strokes to the Empire State Building photographed in 1936, 13 are definitely known to have been initiated by upward stepped leaders, while during the 1937 season, out of 36 strokes to the building 23 had upward stepped leaders. The remaining 4 of the 1936 season could not be identified. All those identified as upward leaders were associated with a continuing stroke. Of the 13 strokes not having upward stepped leaders measured in 1937, two had initial upward continuous leaders and two had initial downward continuous leaders with nine remaining without sufficient data to classify. Of these nine strokes, five appeared only on the oscillograph record, and due to the current being less than 125 amperes initiation was delayed, so if the characteristic current variation during the streamer period had been present it was lost. Three of the strokes occurred during heavy fog and were recorded on the slow-speed cameras very faintly. The ninth stroke was very weak and without discernible leader. Although all upward leaders initiated continuing strokes, and all continuing strokes for which leader data are available had upward leaders, either more data will show downward stepped leaders to the building initiating continuing strokes, or it will have to be concluded that this situation is peculiar to this tall structure.* Although this paper does not include data taken

* This discussion is confined to cases where continuous discharge followed the initial stepped leader. Stroke S-95 (Fig. 31) is a good illustration of continuing current following a subsequent discharge.

FIG. 24.

Downward leader continuing stroke to Cities Service Building with a nearly horizontal portion approximately 2 miles in length. Rotating lens shows initiation leader extending considerably to the right of the building. Aug. 24, 1936.

to other buildings than the Empire State, yet it is important to state for the sake of completeness, that a stroke reproduced in Fig. 24 occurred to the Cities Service Building 950 feet in height, which showed for the horizontal portion at least, a downward leader having a velocity of about 1.5 feet/μs., followed by a continuing discharge. This particular stroke is also interesting in that it had a horizontal portion estimated

FIG. 25.

Multiple stroke consisting of long-continuing low-current discharge followed by 6 non-continuing discharges. Arrow indicates point at which the oscillograph started to record. Stroke No. 16. Aug. 11, 1937.

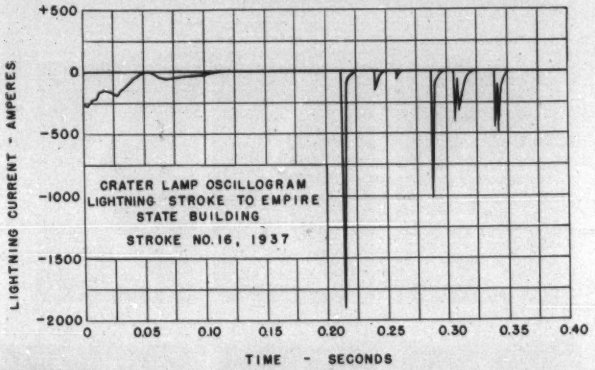
to be two miles in length. This stroke is the only one we have seen in which the leader stroke extended beyond the building top to the right, apparently to branch later to contact the tower. This information is deduced from the rotating lens photographic record.

Of the records obtained of upward initial stepped leaders,

Stroke 16 perhaps is most reproducible, and at the same time complete camera and oscillographic records are available.

The MSB photograph reproduced in Fig. 25 shows the stroke beginning with an upward leader, whose presence can be plainly seen on this record, followed by an illumination which gradually dies out. This is followed by six successive discharges. The oscillogram shown in Fig. 26 was delayed about

FIG. 26.

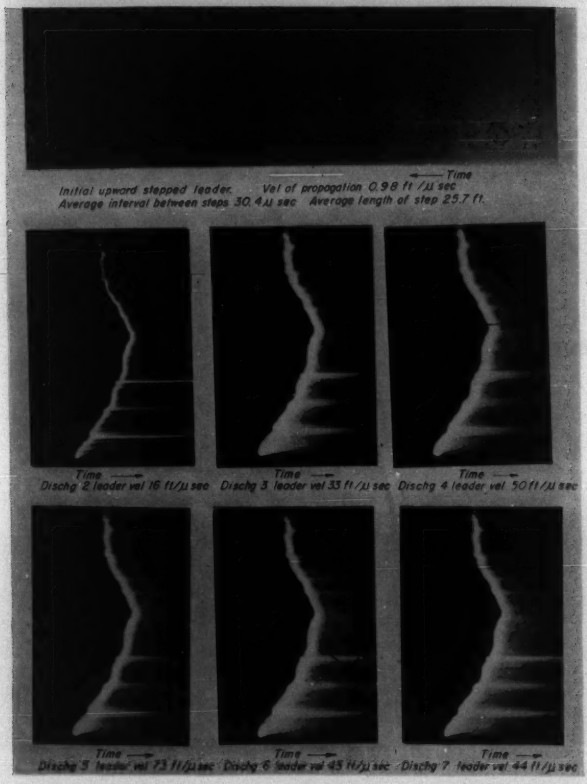


Replotted oscillogram of stroke shown in Figs. 25 and 27, showing 7 discharges for each of which a leader was found.

0.008 second in starting, due no doubt to the small current for initiation. The current after the leader had completed its path was small—being less than 100 amperes for 0.08 second. The last two discharges, which apparently are each made up of two separate discharges, appear from the oscillogram to be one discharge. This is also confirmed by the HSB results.

In Fig. 27 is reproduced enlarged sections of the film taken from the HSB camera for Stroke 16. In the upper record may be seen the initial upward stepped leader, with a velocity of propagation of 0.98 ft./μs., which an average interval between steps of 30.4 μs., and an average length of step of 25.7 feet. Each of the points of illumination resulting from an extension of the streamer will, it is hoped, reproduce so as to be seen when printed. Each of these bright images are connected

FIG. 27.


Time
Initial upward stepped leader. Vel of propagation 0.98 ft /μ sec
Average interval between steps 30.4 μ sec Average length of step 29.7 ft.
Time
Dischg 2 leader vel 16 ft/μ sec
Time
Dischg 3 leader vel 33 ft/μ sec
Time
Dischg 4 leader vel 50 ft/μ sec
Time
Dischg 5 leader vel 73 ft/μ sec
Time
Dischg 6 leader vel 45 ft/μ sec
Time
Dischg 7 leader vel 44 ft/μ sec

Multiple stroke to the Empire State Tower consisting of long-continuing low-current discharge preceded by initial upward stepped leader and six non-continuing discharges all having downward continuous leaders. High-speed Boys camera photographs. Oscillogram of this stroke shown in Fig. 26. Stroke No. 16. Aug. 11, 1937.

with the top of the building with a streamer which is visible on the film in nearly every case, but may not appear after reproduction.

Twenty-three steps are visible. The streamers move upward from the top of the tower at a velocity of approximately 200 feet per microsecond. Almost all of the streamers slow down slightly as they approach the end of their travel, as evidenced by a change in slope of the streamer as drawn out along a time scale by the motion of the film.

No relation could be found between the length of step and the time interval. The minimum length of step was 19 feet and the maximum 69 feet. Most of the steps were close to the average of 25 ft., but considerable error can take place in this measurement, both on account of the smallness of the image and the variations of path in the line of sight. There is no proof that the steps are not substantially constant in length.

Although the time interval varied from 100 microseconds to 20, yet most of the measurements were close to the average 30. The accuracy of these measurements is probably somewhat better than those involving the length of step.

Each of the six following discharges are reproduced in the lower portion of the figure. Each one has a continuous leader, whose velocities are as follows in the order given, in feet per microsecond: 16, 33, 50, 73, 45 and 44 ft./μs.

In Table II is given the velocity of propagation of all upward leaders measured together with the time interval. Also the table shows the existence of downward leaders as measured and their velocity.

Upward stepped leader velocities ranged from 0.17 ft./μs. to 2.09 ft./μs., while downward continuous leader velocities ranged from 1.9 ft./μs. to 128 ft./μs. Two strokes, Nos. 1 and 2 (1937), have been classified as having upward continuous leaders, since no evidence of steps could be found on either the MSB or SSB records, both of which were available. It is possible that if HSB records had been available stepped leaders could have been found. There are some data which do indicate that the time interval between steps may become short enough so as a type it merges into the continuous type of leader.

Although an effort was made to determine if any relation

TABLE II.

Leader and Return Stroke Velocities for Strokes to Empire State Building During 1936 and 1937.

Upward Leaders.		Downward Leaders.	
Velocity of Propagation Ft./μs.*	Average Time Interval between Steps μs.	Velocity of Propagation Ft./μs.	Velocity of Return Stroke Ft./μs.
0.32	—	128	266
0.48	—	29	—
0.17	—	14 (Stepped)	340
0.40	—	38	170
0.53	23	30	180
0.55	—	23	98
0.17	—	—	280
0.51	—	—	115
0.98	30.4	—	230
1.09	—	9.5	150
0.98	—	—	188
0.87	—	15.6	280
2.09	18.6	32.8	270
1.10	—	50	280
0.70	—	73	155
0.55	—	45	280
2.02	24	44	200
0.67	—	—	177
0.80	—	71	119
1.36	—	—	177
		67	177
		16	177
		19	—
		23	212

* This velocity is the length of the stroke (earth to cloud) divided by the elapsed time from the 1st. streamer to leave the building to the 1st. streamer entering the cloud or its equivalent.

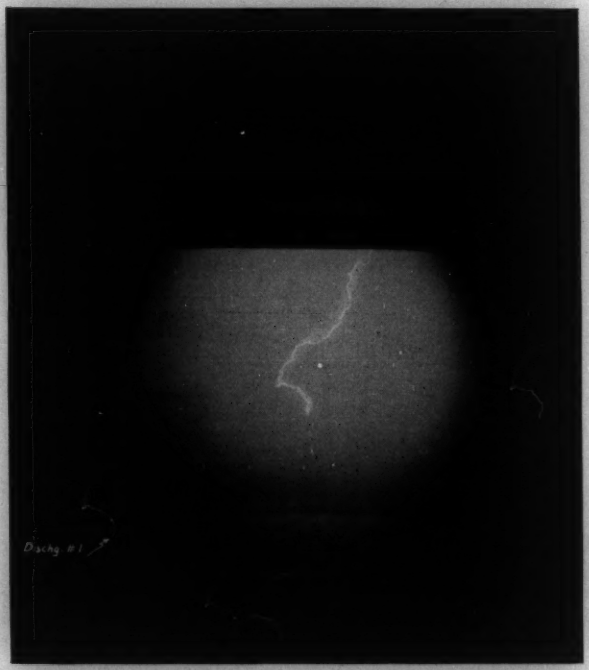
existed between the amount of charge in a stroke and leader characteristics, none could be found with the data available. Likewise the time interval between succeeding discharges could not be definitely related to the velocity of propagation of downward leaders. More data may show some relation between these factors.

DEIONIZATION TIME.

There seems to be little data which would help fix the time required for the air to restore itself to its original insulation value. Perhaps the longest time for the case of a lightning stroke between discharges in the same path would give some indication of the deionization time, assuming of course, that

the current from the preceding discharge was zero during the interval. If the illumination streaks on the SSB and MSB records are used as indications of current flow, which has been

FIG. 28.



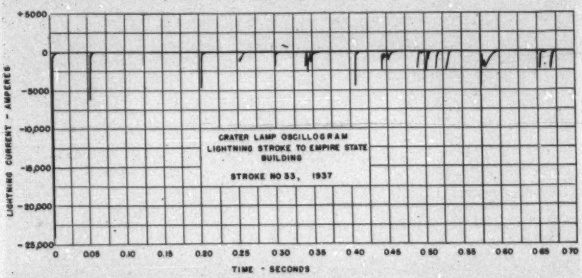
Heavy multiple stroke consisting of 12 discharges. Visibility very poor. Stroke shows marked changes in path. Weak short-circuit path extends across main bend during 1st discharge. Rotating lens image continued for more than one revolution. Oscillogram of this stroke shown in Fig. 29. Stroke No. 33. Sept. 4, 1937.

the practice in working up the data for this paper, the longest * interval of time during which the current was zero was 0.22 (Stroke 34) second. With Stroke 33, the longest time was

* The longest interval measured in Pittsfield was 0.44 seconds (Stroke 48—1936).

0.14 second. The time may be actually shorter than this because a current too small to affect either the SSB record or register on the oscillograph may have been flowing. When photographing both of these strokes, the visibility was not good on account of fog, so that for these strokes it is necessary to rely largely upon oscillographic data for securing the time interval. The characteristics of Stroke 33, having twelve successive discharges of which none appear to be continuing, would strongly indicate that the current did actually fall to zero between discharges. The MSB record of Stroke 33 is shown in Fig. 28 and the corresponding oscillogram in Fig. 29.

FIG. 29.



Replot of crater lamp oscillogram of lightning stroke No. 33. This oscillogram shows the maximum current measured of — 24,000 amps. All of the discharges shown are of relatively short duration.

This type of discharge in which multiple discharges occur might indicate discrete charged cloud masses more or less insulated one from the other, while the continuing type perhaps indicates a rather large charged cloud mass into which at times charges from other masses are discharged, resulting in the superimposed current peaks observed.

Stroke 33 gave the highest current peak measured by the oscillograph with an indicated value of — 24,000 amperes. Although no HSB records are available, it is believed that Stroke 33 was initiated with a downward leader. The impulsive nature of the first stroke of the series, as recorded on the oscillograph, helps to substantiate this probability. Since the antenna insulator did not flash over, the front of the wave

must have been rather slow, perhaps somewhere between 30 and 100 microseconds to reach crest.

In Fig. 30 an SSB record of Stroke 34 is shown partly

FIG. 30.

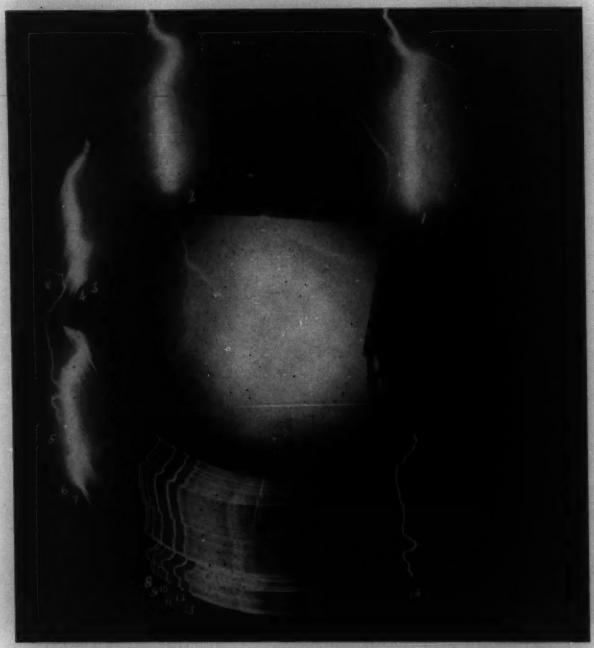
Heavy multiple stroke of 11 discharges with total duration of 1.53 sec. Crater lamp oscillograph recorded only the last 2 discharges. The antenna insulator apparently arched over and remained in a conducting condition for the first 9 discharges. Stroke No. 34. Sept. 4, 1937.

because of its unusual shape close to the building and partly because the time interval recorded between the last two discharges of the series. This stroke is also interesting in that the oscillograph though initiated, did not start recording any deflection until after the ninth discharge. Apparently,

the antenna insulator flashed over, remaining in a conducting condition until after the comparatively long time between the 9th and 10th discharges, estimated to be 0.17 second, after which the insulating value of the air around the insulator was restored and the last two discharges were recorded. The first of these had a recorded current of − 1600 amperes, followed after an interval of 0.22 sec. by another with a crest current of − 4100 amperes. This series of discharges occupied a total time of 1.53 seconds.

Another stroke, shown in Fig. 31, taken in 1936 had a time

Fig. 31.



Multiple and partially continuing stroke obtained in 1936. Leader data not available, although leaders can be seen on branches. All heavy discharges show some tendency for illumination streaks. Discharge 13 has been classified as continuing.

interval of 0.16 second between the first and second discharges, and 0.07 second between the second and third. This stroke is also believed to have been a downward leader stroke, although the data concerning its *initial* discharge are not clear. This stroke will be discussed further under the subject of Branching.

One might think that wind velocity would have something to do with deionization, but many cases are on record where the path has been blown along by the wind, and at least in those cases the path was sufficiently ionized that the discharges still continued in substantially the same path. In a 60-mile wind, the path would move 17.6 feet in 0.2 second. Since the displacement at the electrodes is so small compared to the length of the arc, it is doubtful if the wind has much effect. When sufficient data are available, it may be found that there is a relation between the amount of current and/or its duration, which has an influence upon the time that the path remains ionized.

BRANCHING.

Although no statement can be made on data taken in the New York investigation concerning the effect of polarity on branching, yet with negative cloud, branching has been found both upward and downward, depending upon the direction of propagation. Six of the 27 photographed strokes to the Empire State Building, secured in 1937, show branching, Strokes 22, 24, 29 and 30 being branched upward, while Strokes 28 and 36 are typical of the downward branching type. Strokes 28 and 36 have downward initial leaders, while the other four have upward initial leaders. Figure 32 shows the MSB record of Stroke 29, which may be considered as representative of the group of upward branching strokes, although they differ greatly in detail.

DOWNWARD BRANCHING.

The stroke shown in Fig. 31 (S-95 of 1936) may be regarded as more or less typical of the downward branching stroke, although it is apparently more violent than either Stroke 28 or 36. This stroke had a downward stepped leader, but as indicated by both of the HSB cameras which were operating at the time, it was not associated with the discharge which had the streamers. Based on the appearance of the stroke in

FIG. 32.

Long-continuing discharge terminating in heavy-current peak. Portion of left hand branch is cut off by window at beginning of the rotating image. This stroke illustrates upward branching. Stroke No. 29. Aug. 18, 1937.

Fig. 31, it is quite certain that the discharge with the streamers was the first one. The intensity was so great and so many discharges all appear close to the first discharge, that analysis of the first discharge is difficult. However, the branches in Fig. 31 show in some cases a leader stroke which appears continuous. With the HSB records no leader could be found on the stroke showing the branching, which indicates that it

was too weak to record. In general, the character of the downward branching is quite different from upward branching, appearing as rather short branches only a few hundred feet apart, measured along the main stroke channel.

UPWARD BRANCHING.

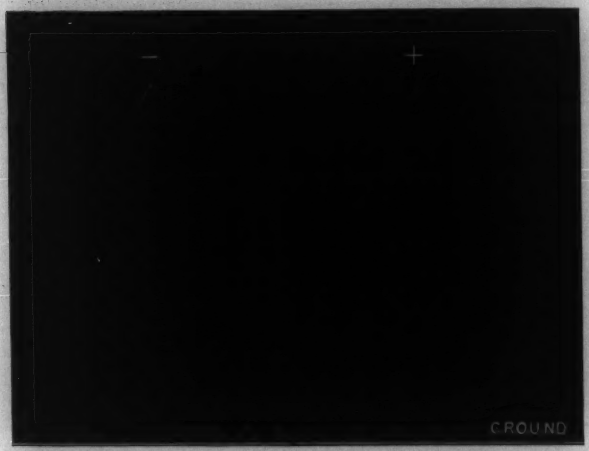
Frequently the upward branches reach out to cover a considerable area, although this is not certainly true in every case recorded. In the case of the path immediately adjacent, no division was recorded closer than 600 feet from the top of the building. A brief history of stroke 29 shown in Fig. 32 may prove to be interesting.

This stroke began at the building—progressing rapidly upward and first forming the path to the left. A total time of 0.024 second was required to complete this path, which is estimated to be at least 10,000 feet in length. The feeder streamers continue to feed into the stroke and another branch forms to the right, and in 0.002 second the right branch is complete. Illumination persists in main channel and branches for 0.224 second—the right branch dies out. 0.108 second later, or at a total elapsed time of 0.358 second since the beginning of the stroke, a heavy discharge takes place, preceded by a continuous leader, reëstablishing the branch to the right, which however dies out immediately. Just prior to the time of this discharge the current as measured by the oscillograph was substantially zero, but increased with a steep wave front to a value estimated to be 3000 amperes—decreasing to zero in about 0.004 second. The illumination from main channel persisted for 0.224 second longer, indicating the presence of a current too small for the oscillograph to record. Making some assumptions concerning the shape of the channel in the line of sight, an average upward velocity of propagation of 2 ft./μs. is obtained for the initial leader. The continuous downward leader had a velocity measured on the MSB film of 4 ft./μs. until it joined the main stroke, when its velocity as measured by the HSB was 23 ft./μs. These results appear to indicate a higher velocity along a path where current is flowing (based on the illumination streaks), than in a path in which the current ceased some time before. Too much faith cannot be placed in these results—particularly not knowing the true

length of the stroke, and some considerable error is possible when measuring the small displacement available on the MSB record. It seems reasonable however, if initial stepped leaders are relatively slow and merge into continuous leaders when the path is somewhat ionized, that with more ionization they would be still faster. Stroke 29 had a measured charge of 99 coulombs, which is much above the average measured.

In the laboratory when causing an impulse to pass a gap between point and plane, the discharge reaches from the point to the plane, irrespective of polarity, as seen in Fig. 33, which

FIG. 33.



Appearance of discharge in the laboratory under normal atmospheric conditions between point and plane. Separation 16½ in. Right point negative. Left point positive.

shows discharges of both polarities with a spacing of 16¾ inches. Matthias [20] showed that with small points up from the plane, small streamers took place. These results are similar to the record of a lightning stroke to a New Jersey beach close to the water, taken in August, 1934. This photograph, Fig. 34, shows branching downward of the stroke itself, which no doubt existed as a part of the leader. The

FIG. 34.

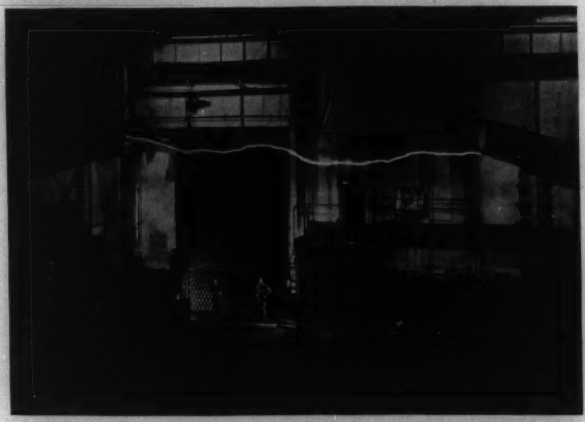
Lightning striking beach in New Jersey, August 1934. Stroke occurred about 100 ft. from camera. Forked streamer on right is about 6 ft. long. Streamer on left is 4 ft. long. Division of main stroke and the smaller streamer extending upward from it are about 8 ft. above ground.

streamers from the ground are branched upward, including the streamer with which the leader made contact. This may be plainly seen by examining the original negative. This all indicates that the ground streamers existed just prior to the

time when the leader made contact with the longest streamer. After this they disappeared, after having left their impression on the photographic film.

When a discharge from an impulse generator in the laboratory is passed between pointed electrodes, a separation very often appears near the middle of the gap. This is illustrated very nicely by Fig. 35 which shows a discharge between

FIG. 35.



Ten-million-volt artificial-lightning discharge in high-voltage engineering laboratory of Pittsfield Works. Energy output equals 125,000 watt-seconds. 30 ft. between electrodes.

electrodes nearly 30 feet apart. Since branching occurs directed toward the middle over most of the length of the stroke, it appears that the direction of propagation was from either end meeting approximately in the middle. The division near the middle of the stroke is also evidence of the same phenomenon. A similar division is observed in Fig. 36 where a succession of discharges across a 100 inch point gap have been photographed. These results, coupled with the results recently published by Allibone,[22] seem to indicate that branching is in the direction of propagation and substantially independent of polarity.

FIG. 36.

Series of discharges across 100 in. vertical needle gap using 1.5/40 impulse taken with SSB camera.

If direction of branching can be taken as an indication of the direction of propagation, in the many cases where still photographs are available, but no moving film records have been taken, considerable progress will have been made in the analysis of wave shapes of current reaching transmission lines and similar structures, assuming that the rate of propagation

and amount of charge determine the wave front and crest current.

MAXIMUM CURRENTS MEASURED.

Table III shows the values of current measured with the magnetic links during the four years they have been in use.

TABLE III.

Maximum Currents Measured with Magnetic Links Empire State Building, 1935 Through 1937.

Date.	Maximum Current (Amperes).	Number of Strokes Represented.
June, 27, 1935	−27,500	1
July 19, 1935	−40,000	2
August 23, 1936	−105,000	11
August 17, 1936	−89,000	1
May 13, 1937	−156,000	
June 2, 1937	−117,600	
July 11, 1937	−88,200	3
July 26, 1937	−129,500	8
August 11, 1937	−89,600	19
August 18, 1937	−132,300	5
September 4, 1937	−105,000	6

Note: Current values indicated for 1936 and 1937 represent summation of all current values measured in the different parallel paths represented by the antenna structure on top of the building.

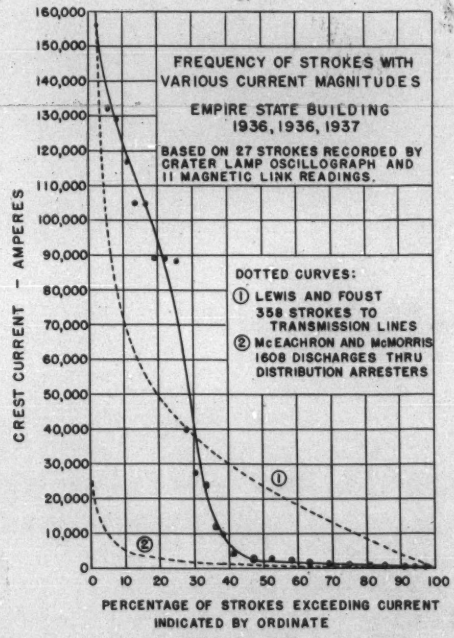
In Fig. 37 is plotted the frequency of occurrence of currents of various magnitudes, whether measured by the oscillograph or through the use of magnetic links. Plotted with this curve is one taken from the most recent data of Lewis and Foust [2] for transmission lines, and from McEachron and McMorris [23] for currents through lightning arresters connected to distribution circuits.

DISCHARGE PATH.

Since the electrostatic field is along smooth curved lines, it is very evident that lightning, and for that matter sparks in general, do not follow the direction of the field. This is due to the fact that breakdown is not simultaneous over the length of the path, and the progressing streamer picks out the best path from instant to instant, resulting in the crooked path so familiar to one who studies lightning. This being so, it is not

difficult to visualize why lightning does not always strike the highest object. In those cases where upward leaders determine the path, the stroke will presumably be from the highest point. However, in the case of downward leaders, the best path may not be the shortest path, and the attractiveness

FIG. 37.



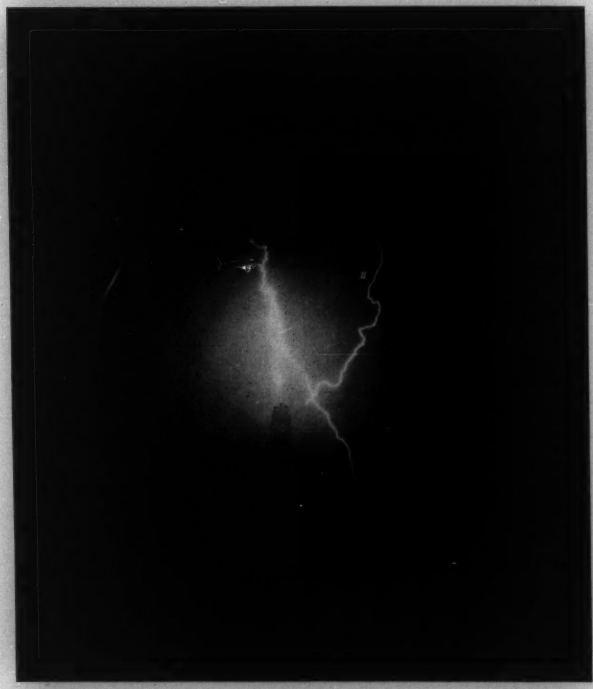
Frequency of occurrence of strokes of various current magnitudes as determined by three different investigations as indicated.

of one path over another may change even during the progress of a multiple stroke. This was beautifully illustrated by an early photograph by Walter [24] of a stroke with a still camera and with a camera being moved horizontally. The first discharge of the series came almost straight down, but all of

the succeeding discharges, progressed part way over the old path and then left to take a new path to the ground.

The first stroke of this type to the Empire State to be

FIG. 38.



Two strokes I and II to the Empire State Building, the cameras having been moved between the two strokes. I consisted of at least 4 discharges. The first of the series struck a building 360 ft. high and 1200 ft. west of the Empire State. Remaining discharges contacted the building. Aug. 1936.

photographed is shown in Fig. 38 (S-88) and was taken in August, 1936. Two strokes to the building appear in this record—the camera having been moved between the two.

Unfortunately at the time the stroke on the left occurred the moving lens had closed so no detailed record is available of what happened. However, the record from the still lens tells an interesting story. The path of the stroke is displaced sufficiently so that four discharges may be seen. The first discharge of the series struck a building 360 feet high and 1200 feet West of the Empire State Building. Since this first discharge is branched downward it is presumed that in the light of present knowledge it had a downward leader. The three following discharges left the path of the first discharge at a point 655 feet above the building—the first discharge to reach the building showing at least one downward branch approximately 550 feet above the building. The remaining discharges had no branches which could be detected. It may be that a streamer built up from the building which changed the course of the succeeding discharges, but there is no evidence to support this idea, except it is what one would expect.

During the 1937 season Stroke 33, Fig. 28, for a distance of 200 feet above the building, showed a shift in path about five times as great as could be accounted for by the wind velocity which was about 80 miles per hour at the time. This stroke was also unusual in that a close examination of the negative shows that the first discharge of the stroke had a streamer which appeared to extend all the way across the bend in the stroke close to the tower. For some reason or other the path was not shortened by the development of the streamer—rather it was not visible on the subsequent discharges.

Out of a total of 46 strokes recorded to the building, no stroke has terminated within a cone whose base radius on the ground is 1200 feet, excepting one which terminated 16 feet down from the top of the antenna. The Gaty [16] photograph referred to in the beginning of this paper is the only other known stroke which failed to strike the top and struck within the cone.

UPWARD STREAMERS WITHOUT CONNECTING STROKE.

Two upward streamers from the Empire State Building which did not result in a stroke to the building were photographed in 1937. One of these was about 300 feet in length,

and apparently took place at the time of a cloud to cloud discharge. Details are lacking on account of the poor visibility at the time. The other streamer occurred at the time of a single cloud to cloud discharge when a branch downward came within 400 feet of the top of the building. The upward streamer from the building top extended to within 130 feet of the downward branch.

One upward streamer was also photographed in 1936 extending 85 feet upward from the Metropolitan Life Building which is a structure 657 feet high and situated 2100 feet from the Empire State Building. The same film also shows a stroke with upward leader from the Empire State and one with an upward leader from Cities Service Building.

CLAYDEN EFFECT.

In some cases of initial streamers and in two cases of stepped leaders photographic reversal or Clayden effect was observed. It was not possible to tie up this effect with the amount of exposure before or after the lightning discharge. It is mentioned here only as a matter of record.

THUNDER.

During 1935 the engineer operating the camera reported that on two occasions he saw strokes to the Empire State Building, but did not hear thunder as it is usually identified. He reported a sound which he described as being the same as though a paper bag full of water had been dropped for a short distance. Upon further investigation it was recalled that the Superintendent of Buildings in Washington had reported [25] that in 1885 lightning struck the Washington Monument without audible thunder. In the light of what is known now, it appears that lightning without the usual thunder will result from the upward streamer of small magnitude followed by a continuing stroke without any steep current peaks. Such a continuing stroke, which is really a D.C. arc, might well give the appearance of a severe stroke of lightning without much, if any, thunder in the ordinary sense. In many cases during the 1936–7 seasons, the noise of the high-speed cameras was such that observations on thunder were often unsatisfactory.

CLOUD TO CLOUD STROKES.

A discussion of lightning strokes would not be complete without some mention of cloud to cloud strokes and many were photographed. Perhaps the most interesting one, shown in Fig. 39, took place in 1935 and occurred while the camera shutter was open waiting for the stroke to the building, which, by the way, was a single continuing stroke with an

FIG. 39.

Stroke to Empire State Building, New York, and cloud to cloud discharge taken with both still and rotating lens. Two strokes appear in this photograph—I to the building, and II is the cloud to cloud discharge. The progressive phase of this discharge has been indicated by subscripts to II. The long continuing discharge following II_{11} is of interest.

upward leader. The dark space following some of the upward streamers from the building may mark the end of one branch and the succeeding streamers seen indicate the formation of another branch out of range of the camera. Or, possibly this hesitation in the streamers may be an arrested continuation of the original stroke.

The cloud to cloud stroke was 6000 feet in length at least. The film was not wide enough to catch all of the image of the stroke from the rotating lens which it will be recalled was making one revolution per second during the 1935 season. Comparing the still lens image with that from the rotating lens, it becomes apparent that the stroke began as a very weak continuing stroke, beginning with the straight portion just above and to the left of the image of the Empire State Building. The discharge path extended in both directions changing shape somewhat and 0.183 second later when the current had almost, if not altogether ceased, a discharge occurred which has been marked II_2 on the film. The right hand part of the path of this discharge is quite similar to the path seen in the still picture, the path to the left is quite different in detail.

The third discharge II_3 roughly 0.02 second later developed branches to the left at a point almost directly in line with the top of the building, on the film; the main channel to the right which appears just underneath II, appearing very faintly. Other changes in path occurred as the successive discharges continued until after a total elapsed time 0.422 second, during which time one continuing and 12 multiple dicharges took place, a long continuing stroke began with fairly steady current flow through most of its existence of 0.411 second. At the beginning of the first continuing discharge no leader could be identified, nor could any be found at the beginning of the second continuing discharge, but in the light of the appearance of the upward streamers with so many continuing strokes, one might conclude that possibly leader strokes were present during the beginning of the second continuing discharge.

This stroke is interesting because among other characteristics it demonstrates that cloud to cloud discharges may be continuing or multiple, which seems to indicate that the determining factor as to whether or not a discharge to ground

is to be multiple, single or continuing does not reside in the earth or its resistivity, but is profoundly influenced by conditions in the cloud. This does not preclude the ground resistance from having some effect, but the type will in general be determined by the cloud conditions, and not by earth conditions.

One would expect that cloud to cloud discharges would have leader strokes, and Schonland, Malan and Collens [11] have shown both stepped and continuous leaders. Leaders have also been identified on several cloud to cloud strokes photographed in New York City. Propagation velocities were not measured as the distance to the stroke was not known.

STREAMER CURRENTS.

The velocities of upward stepped leaders fall within the limits measured by Schonland for downward stepped leaders, and the time intervals are of the same general order of magnitude. The downward continuous leaders had velocities also within the limits obtained by Schonland and ourselves when measuring strokes to open country. These comparisons lead one to believe that as a first approximation the streamer currents from the top of the building will be of the same order of magnitude as those which move downward from the cloud in the stepped leader.

A consideration of the data seems to indicate that the stepped leader seems to have about the same characteristics whether upward from a well-grounded building or downward from a cloud having charges residing upon the surface of drops of water or ice particles more or less insulated from each other. Since the lack of mobility of charges within the cloud will have but little effect upon the mobility of charges in the earth, it is reasonable to conclude that the mechanism of the stepped leader is not peculiar to the cloud and its formation, but would have existed if the cloud had been a conducting body with a point of concentration provided by a long conducting needle pointing toward the earth.

Again consider the upward and downward leaders from another point of view. As seen from the earth end a downward leader attached to the cloud through a streamer starts an upward moving main stroke following contact with the

earth. The velocity of the streamer is known, also the velocity of the returning main stroke. As viewed from the cloud end a time interval of several hundred microseconds would elapse before the main stroke reached the cloud. If conditions are the same for the upward leader one might expect a similar waiting time before the return of the main stroke, of at least half of that time if the leaders were both downward from the cloud and upward from the building. But no such time interval has been found, the last upward streamer merely becoming more intense and developing into the main stroke. What this means when applied to the downward stepped leader as viewed from the cloud end the author does not know; perhaps additional data will supply the answer.

SUMMARY.

No effort will be made to make a complete summary of the results of these three year's work in New York City, only some of the most important items being given.

1. Oscillograms and/or moving film Boys camera photographs have been taken of 55 strokes to the Empire State Building.

2. Direct current arcs, with or without superimposed current peaks, extending between the cloud and the building continuing as long as 0.4 second, have been measured. These we have called continuing strokes.

3. Upward leaders from the building which developed into continuing strokes have been photographed and data as to velocity of propagation secured. (Upward leader velocities range between 0.17 ft./μs. and 2.09 ft./μs. with an average of 0.84 ft./μs.)

4. Currents measured during build-up of upward stepped leaders range from 50 to 650 amperes.

5. Branching was found to be in the direction of propagation of initial leader strokes.

6. At least 50 per cent. of the strokes had a charge of 35 coulombs or more with a maximum of 164. These values are several times as large as heretofore believed probable.

7. All strokes to the building began with the cloud negative. 3 strokes changed to positive at or near the end of the stroke. About 3 per cent. of the total charge measured was associated with the positive portion of the strokes.

8. Downward stepped leaders to the building were observed in one case only which had a velocity of 14 ft./μs. A stroke to a building 200 ft. in height had a downward stepped leader velocity of 5 ft./μs.

9. Leaders on all discharges after the first were always downward whenever found, whether the initial leader was upward or downward. Such downward leaders had velocities ranging from 1.9 ft./μs. to 128 ft./μs. with an average of 39 ft./μs.

10. Return stroke velocities following initial stepped downward leaders were 340 ft./μs. and 150 ft./μs. in the two cases recorded, while the return stroke velocities following continuous leaders ranged from 98 ft./μs. to 280 ft./μs. with an average of 197 ft./μs.

11. Every stroke, but two, of which the author has record, either struck the highest point on the building or outside a cone whose base radius at the ground level of the building was equal to the building height.

CLOSING DISCUSSION.

The picture of a lightning stroke as it appears to the author at present is something like the following.

The majority of lightning discharges photographed in the past were branched downward, indicating downward leaders, which is to be expected when the earth is more or less a plane surface as regards the cloud, which due to its construction automatically begins to act as a needle point as the charges accumulate in some part of the cloud. The discharges proceed from the cloud in a series of steps, always being fed by a streamer from the original cloud. As this streamer progresses, choosing the best path, the charges upon the earth's surface begin to flow into the region of increased field strength due to the approaching streamer. When the field strength becomes sufficient, streamers will form from grounded objects on the earth's surface. The stroke will usually contact the longest streamer; the return stroke follows, in which charges from the earth will pass up the stroke channel, their flow constituting the current in the discharge. The front of the wave will depend upon the rate at which charges flow into the point to be struck. The crest current will be determined by the

number of charges flowing into the channel at the time of contact, and if the stroke is to be continuing, charges will continue to flow until the supply is exhausted in either the earth or the cloud.

Thus the front of the wave of current of a lightning discharge with initial downward leader to a transmission line is probably dependent upon the amount of charge and the rate of its propagation toward the point to be struck, while the tail of the wave is dependent upon the amount of charge available. It is not known whether the percentage of strokes to open country which are continuing, is as great as to the Empire State Building or not, but it is known that they do occur frequently, and are probably dependent to a large degree upon the distribution of charge within the cloud for their existence. If it is true, as suggested, that the maximum current in a discharge with a downward leader will occur (unless some new cloud charge is tapped), when that leader makes contact with either the earth or a short streamer from the earth, the magnitude of that current will be determined by the charge in the earth and its availability. The amount of charge in the earth will be related to the amount of charge in the cloud and so will the maximum current. A considerable portion of the charge associated with the particular stroke will move from the cloud down into the channel created by the leader. This channel of charges will extend all the way to the earth to unite with the charges from the earth when contact is made. This reasoning would lead one to believe that continuing strokes with downward leaders would be likely to have an initial peak followed by the more or less steady current flow due to the partial or complete discharge of the cloud center.

Presumably discharge starts from the cloud without being much influenced by the earth configuration, but as it approaches it is more and more influenced, although as a rule that influence is local in character. However, the taller the conducting object the greater its influence. With strokes initiated by upward leaders, the case is different. It is believed that upward leaders will only occur when conditions on the earth simulate a needle point of sufficient height to have an influence on the propagation. Perhaps some natural configurations of the earth might be of such a nature as to produce the upward leader.

It seems to the author, however, safe to state that the downward leader stroke represents the type of stroke of greatest importance in the problem of protection of transmission lines and apparatus.

The effect of the continuing type of stroke must be determined. It seems that it will not be of great importance on grounded neutral electrical systems, because the continuous current can readily flow to ground through the transformer windings. The isolated neutral system may have trouble with protective apparatus connected to ground. Just how important this matter of continuing strokes will turn out to be is not known at present, but it may help explain some of the failures of lightning arresters attributed to arcing grounds or other system disturbances. The continuing type of discharge may have considerable effect on the blowing of fuses used to protect distribution transformers when operating grounded neutral.

The amount of charge involved in the continuing stroke gives some idea of the amount of charge in a cloud center. Assuming a crest current of 200,000 amperes and a time to half value of 50 microseconds, the coulombs would be but twenty, which is less than the average obtained in New York. However, this difference is to be noted. These large amounts of charge result from the relatively long times involved, which possibly suggests that only a part of this charge would be available for a high current short time discharge. All of this indicates the extreme importance of measuring the characteristics of the down-leader type of stroke. Several of these occurred to the building this year, but in all cases but perhaps one, flashover over the antenna insulator resulted. It is hoped that suitable changes can be made for the 1938 season so that this flashover will not occur.

It is also important to determine the streamer currents more accurately, which will be done during the 1938 season using a cathode ray oscillograph instead of the magnetic oscillograph.

It is also planned to attempt a correlation between the photographic intensity and the current in the stroke. If practicable, this would greatly extend the field of the observations.

ACKNOWLEDGMENTS.

The author and his associates wish to express appreciation to the National Broadcasting Company and their engineers, particularly R. M. Morris and T. J. Buzalski, for making it possible to take measurements of lightning currents through the antenna, and allotting space in the top of the building for the oscillographs.

Fletcher and Ellis at 500 5th Avenue kindly made available space in their offices for housing the photographic equipment. Thanks are also due to Mr. Neave of the same organization for his fine coöperation.

The author wishes especially to call attention to the part played by Mr. R. M. Partington, Mr. F. B. Headley and Mr. A. C. Sugden, who successively operated the equipment during the three summers. Mention should also be made of the assistance of Mrs. Sugden during the 1937 season. Mr. J. H. Hagenguth and Mr. C. J. Kettler deserve special mention because of their assistance in designing and building the equipment used. Mr. John Russ has been of much help in assisting in the preparation of this paper. Mr. J. B. Bassett and other associates deserve the author's sincere thanks for their kind assistance in connection with this investigation. The assistance of the U. S. Weather Bureau and the Public Service Co. of New Jersey is acknowledged with thanks.

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Federal Program Creates New Opportunities in Engineering N. Y. U. Dean Reports.—The new opportunities for engineers created by governmental expansion will require significant readjustments in engineering education, Dean Thorndike Saville of the New York University College of Engineering declared in his annual report to Chancellor Harry Woodburn Chase. At the same time, Dean Saville added, public authorities must devise more effective means for recruiting qualified engineers into the public service. The major tradition of engineering education has been to provide trained men for private industry, and while the obligation to contribute properly qualified young men to design, operate and manage private enterprise is still an important and compelling one, the enormous expansion of governmental activities has provided a new directive for engineering education which has as yet been inadequately reflected in most engineering colleges. Public regulation of private enterprise and the construction of public works on a greatly increased scale are providing new opportunities for the engineer which require significant readjustments in training. On the one hand we must preserve the fundamental scientific background and rigorous adherence to facts which constitute par excellence the characteristics of an engineer. On the other hand economics, labor and social problems, finance, and administrative practices must be appropriately introduced into the curriculum. This is no mean task for the modern engineering educator.

R. H. O.

Eskimo Igloo to be Erected at World's Fair by Carrier.—(*Refrigerating Engineering*, Vol. 36, No. 4.) Towering higher than a five-story building, a giant Eskimo Igloo with "snow" encrusted walls and the Northern Lights playing from its ceiling will be built by Carrier Corporation as its exhibit at the 1939 World's Fair in Flushing, N. Y. The Igloo will be 70 ft. high of white stucco with a crystal finish to simulate snow. Surrounding the Eskimo house will be pools, which at night will reflect the floodlights playing on the Igloo.

R. H. O.

PRINCIPLES OF ROTARY AIRCRAFT.*

BY

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I. INTRODUCTION.

The death of Senor Juan. de la Cierva was a great blow to rotary aircraft. He was a gentleman of the most charming personality, a man of great mathematical and inventive genius, and far from resting on the laurels of his earlier achievements, he continued the development of the autogiro up to the day of his death (in an airplane accident), and was responsible for a great many of the latest improvements. His loss is irreparable, and many people not professionally interested in aeronautics have drawn the conclusion that rotary aircraft would now cease progress. This impression is erroneous, as the following review of fundamental principles and recent achievements will perhaps indicate. The present paper may also serve as a starting point for the study of the immense field of applied aerodynamics already constituted by rotary aircraft.

II. THE CLASSIFICATION OF ROTARY AIRCRAFT.

As a further introduction, it may be appropriate to attempt a classification of rotary aircraft, though it is too much to hope that such a classification should be either complete or free from criticism.

1. Autogiros and Gyroplanes.

These are closely allied types, exemplified by the De La Cierva autogiro and the Wilford gyroplane. In both autogiro and gyroplane, the rotor is autorotative and no power is supplied to it except in starting up the rotor. Both types have substantially two degrees of freedom with rotation about a vertical or rather normal axis. The autogiro blades have a

* Presented at a meeting held Thursday, October 27, 1938.

flapping or up and down motion about a horizontal pin which lies roughly parallel to the chord or width of the blade. The gyroplane has blades which oscillate or feather about axes parallel to the span or length of the blades. But the autogiro pin may be placed with the hinge pin at an angle other than 90 degrees to the span, so that it has some feathering as well as flapping motion, and the gyroplane may oscillate about an axis so disposed that on the feathering motion some degree of flapping is superimposed. In the autogiro a condition of autorotative equilibrium in which the blades rotate without application of power is achieved by a combination of aerodynamic forces and moments, gravity and centrifugal force and no moments are transmitted to the machine from the rotor, while in the gyroplane autorotative equilibrium is either a matter of aerodynamic balancing of blades on either side of the vertical axis or the result of mechanical controls, and moments are transmitted to the fuselage. Nevertheless it is quite clear that autogiros and gyroplanes belong to the same subdivision of rotary aircraft, and tend to merge into one another.

2. The True Helicopter.

The name Helicopter should be applied, in our opinion, solely to that type of aircraft in which power is applied to the lifting airscrew, in which the axis of rotation is inclined forward to secure forward thrust, and in which no propulsive airscrew is employed.

3. Helicogyro.

The Helicogyro seems to be an apt name for that type of machine in which a power driven airscrew to provide lift is combined with a propulsive airscrew of the conventional airplane type.

4. Cyclogyro.

The Cyclogyro is the name given to that type of aircraft in which the axis of rotation of the blades is horizontal as in a paddle-wheel, and the power-driven blades, mounted at the end of long arms, oscillate in a manner determined by cam settings so as to provide both lift and propulsion.

5. Combination Helicopters and Airplanes, Helicopters and Airships

At various times attempts have been made to build combinations of lifting power driven airscrews with fixed wings, and of direct-lift airscrews with lighter-than-air craft. Such combinations have never been of much promise, and are merely included for the sake of completeness. The Herrick Convertoplane belongs to quite a different category, however, and has considerable significance.

III. AUTOGIROS AND GYROPLANES.

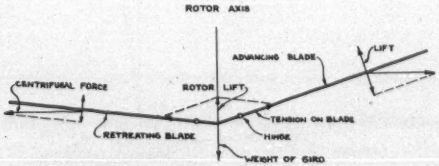
1. Fundamental Conception of Autorotation.

The fact that the autogiro or gyroplane is a giant windmill, which supplies lift by continuous autorotation of its blades once it has attained certain rotational and forward speeds is now well understood. Nevertheless it may be useful to recall the basic principles involved.

Autogiro or La Cierva Rotor.

The principles of the autogiro rotor (as finally developed by La Cierva after passing through intermediate stages of rigid rotor and then flexible rattan blades) are illustrated in the sketches. The diagram of Fig. III-1 indicates the

FIG. III-1.

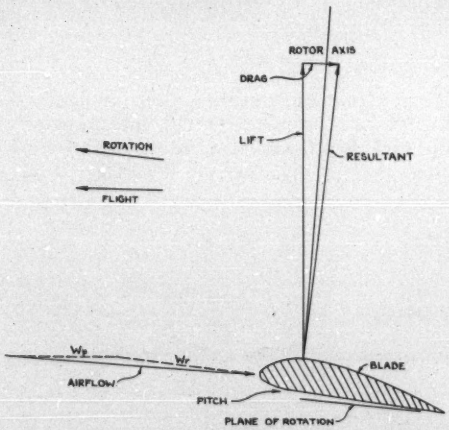


Illustrating the equalization of lift in the La Cierva rotor.

elements of the La Cierva rotor. The blades are free to rotate about a substantially vertical axis, and are also freely hinged about horizontal pins or axes. They may also have some slight freedom to advance relative to one another in the plane of rotation, but this is a subsidiary characteristic, which need not be discussed here. The equilibrium of the system is readily understood. The dynamic forces on either blade are

two-fold: the gravitational force or weight, and the centrifugal force. The aerodynamic force mainly involved in the problem of equilibrium is the lift. Were the blades not freely hinged at their roots, the lift on the blade advancing into the wind would be greater than the lift on the blade retreating from the wind and a rolling or capsizing moment would be introduced. But since the blades are freely hinged, the advancing blade rises and in so doing diminishes its effective angle until equilibrium of lift weight, and centrifugal force is established. The retreating blade also rises (though to a lesser extent) until its equilibrium is also established. Since weight and centrifugal force are equal on either side, and since lift is the resultant of weight and centrifugal force, lifts on either side

FIG. III-2.



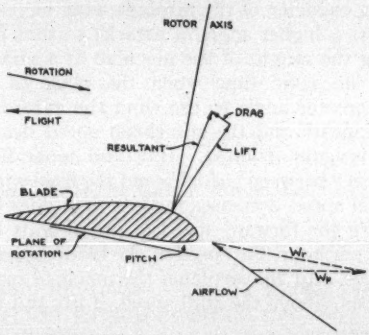
The advancing blade of the rotor. A section of the blade acted upon by anti-autorotative forces.

are equalized, though not completely so. And the resultant lift of the two blades passes very nearly through the axis of rotation. The substantial equalization of the lift explains why de la Cierva succeeded so well with his hinged blades, eliminating disturbing moments, while unable to achieve flight with a rigid rotor. The above explains the familiar

"coning" of the autogiro, giving a form similar to that of an inverted umbrella though the degree of coning varies with the position of the blade in its plane of rotation.

Figure III-2 illustrates the production of "anti-autorotative" forces on the outer portion of the advancing blade. In this diagram the wind stream due to the general motion of the aircraft is seen to be horizontal, while the axis of rotation of the rotor is inclined slightly back of the vertical, so that the plane of rotation makes a certain angle with the horizontal. The resultant wind, compounded of the relative wind of forward motion, and of the relative wind of rotational

FIG. III-3.



The retreating blade of the rotor. A section of the blade acted upon by autorotative air forces.

motion makes a smaller angle with the horizontal than the plane of rotation. Hence the lift vector, which is perpendicular to the resultant wind, is a head of the axis of rotation which is at 90 degrees to the plane of rotation. Nevertheless when the drag of the advancing blade is taken into account, the resultant vector of lift and drag falls behind the axis of rotation, and hence an anti-rotative force is brought into play.

Figure III-3 illustrates the resultant flow, and the direction of the resultant vector on an element of the retreating blade. The resultant vector is now seen to fall ahead of the axis of rotation and hence an autorotative force is produced.

Of course it is only after a certain speed has been attained by the rotor under the action of a starting mechanism that the autorotative force on the retreating blade overcomes the anti-autorotative force on the advancing blade. Thereafter the blades may be left to themselves, speeding up until equilibrium is established. The introduction of a starter by de la Cierva was an inevitable step which was carried to final achievement by American mechanical ingenuity at the hands of Pitcairn Autogiro Company.

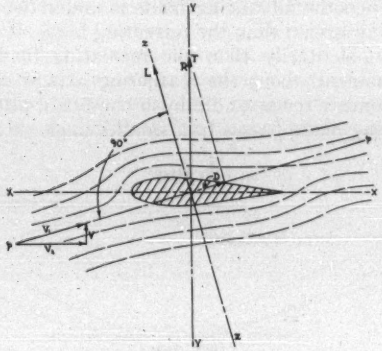
The rotor readily adjusts itself to varying speeds of flight. If the plane of rotation is placed at a greater angle to the wind of forward motion by tilting back the axis of rotation the lifting capacity of the rotor for a given speed increases (just as the lifting capacity of the airplane wing increases when it is disposed at a higher angle of attack) so that it is capable of sustaining the weight of the machine at a smaller forward speed. At the same time when the plane of rotation is placed at a greater angle to the wind the autorotative equilibrium disappears and the rotational speed decreases until equilibrium is again attained. But (and herein lies the heart of the difference between autogiro and the fixed wing airplane) the rotational speed decreases far less than does the forward speed. When the forward speed of the aircraft has sunk to say 20 miles per hour, the speed of the blade tips may be well over 150 miles. In the airplane, the machine must move at a certain speed, above the stall speed, if lift and flight are to be maintained.

It is in this virtual disassociation of the forward speed from the blade tip speed, that we find therefore a real point of superiority over the airplane in the autogiro.

This disassociation goes so far that autorotation and a large lift capacity are available when there is no forward speed at all, so that relatively slow vertical descent becomes possible. The possibility of autorotation (with which high lifting capacity is associated) is illustrated by the diagram of Fig. III-4. In this case all blades function in an identical manner, with equilibrium established when the rotational velocity and the vertical velocity are such that the resultant of the lift and drag, the axis of rotation and the vertical line of gravity all coincide. Our diagram indicates that the blade

angle is at zero or even a slightly negative angle to the plane of rotation. This fact explains why a power-driven helicopter

FIG. III-4.



Autorotation in vertical descent.

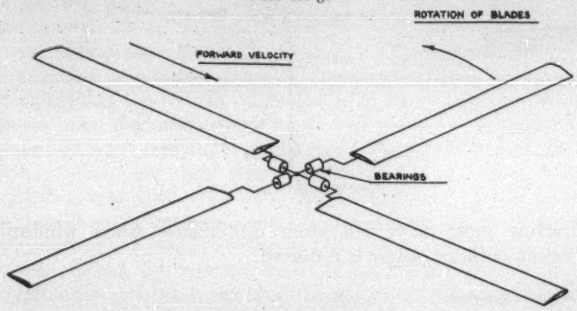
airscrew must have its pitch diminished when windmill descent without power is required.

The Wilford Gyroplane.

The Wilford rotor was discovered several years after the Cierva rotor had already reached a fair stage of development, is not so well known and has not yet advanced to the same maturity. Its rotor is however substantially the aerodynamic equivalent of the Cierva rotor, and the mechanical feathering control invented by E. Burke Wilford is claimed to be the forerunner of the Hafner control. The basic principle of the Wilford rotor is illustrated in Fig. III-5. There are four blades, symmetrically disposed two by two, and interconnected, which feather or oscillate about an axis substantially parallel to their span. All blades are initially at the same pitch angle. Autorotation is obtained when the axis of rotation is inclined a few degrees back from the vertical and sufficient rotational speed has been obtained—in much the same manner as in the La Cierva rotor.

The Wilford rotor differs however in the manner in which equalization of lift and moment is obtained. The axis of rotation of the blades is placed slightly ahead of the center of pressure of the symmetrically double cambered airfoils of the blades. When the advancing blade is under the action of a more rapid airstream than the retreating blade, it experiences more lift momentarily than the retreating blade, but the resulting moment about the feathering axis is also greater, and this moment tends to diminish the blade pitch. Hence the advancing blade passes to a smaller angle of attack, and

FIG. III-5.



Principle of the Wilford rotor.

the retreating blade goes to a higher angle. Thus there is equalization of lift and moment.

The Wilford gyroplane began with purely natural equalization of the moments, but it was soon found that mechanical feathering in which changes in pitch at various angular positions in the plane of rotation were predetermined was more effective, and permitted autorotation at lower angles of attack of the disk area as a whole. The mechanical feathering, which will be discussed a little later, also serves as a fine method of direct control. The Wilford gyroplane has been flown both as a land plane (Fig. III-6) and as a seaplane on order for the Navy Bureau of Aeronautics, always with a fixed wing, which however does not seem to us to be an essential part of the aircraft.

While wind tunnel tests indicate that the Cierva and Wilford rotors are aerodynamically equivalent, there are many arguments pro and con for their respective uses.

Thus, in the Cierva rotor the structural problem is much simpler since there are no bending moments at the hinge, and the free rotor so adjusts itself in a bank or pitch that no gyroscopic moments are transmitted to the fuselage. The Wilford rotor is apt to be heavier, since bending moments are transmitted to the root, even though these moments are relieved by the flexibility of the blades and the moments due

FIG. III-6.

Early example of the Wilford gyroplane.

to centrifugal forces, when the blades flex and while gyroscopic couples moments can be offset by appropriate movement of the controls, their natural elimination seems preferable. On the other hand with the Wilford rotor there is no excessive coning or drooping to be feared, no oscillations in the plane of rotation have been encountered, and no interblade bracing has been found necessary. From an efficiency point of view it has been claimed that with the small amount of feathering required, there is a smaller equivalent frontal area in the gyroplane rotor than in the autogiro rotor. The Wilford rotor could if required be brought to complete

rest, and allowed to fly on the fixed wing, so that resistances at high speed would be those of fixed surfaces only and this has been advanced as an argument for high speed; but the writer does not believe that to provide two lifting systems, one of which is to be completely parasitical at high speeds, is a logical method of attaining high speeds. The possibilities of the Wilford rotor appear to lie in the following directions:

1. It should lend itself readily to high loadings, and low solidity (if adequate strength can be obtained).

2. With introduction of some minute power it could be made to rotate at very low angles of attack of the disk area, and hence provide efficiency at high speed.

3. There is freedom in changing rotor design, since there is no delicate balance of weight, centrifugal force and aerodynamic forces to be kept in view.

4. Since the direct method of control, already available, consists in blade pitch variation, the Wilford rotor would lend itself readily to the process of energy assisted control (to be discussed later) and to obtaining a well regulated system of direct take-off.

5. The controlled rotor would lend itself readily to use in the helicopter, where blade angle variation is an essential element of control and of transformation from the power-on condition to the condition of vertical ascent without power.

6. The Wilford control if it could be applied to a Cierva rotor might be an alternative to the tilting of the rotor. The Wilford rotor deserves further research.

Hafner Rotor

The Hafner rotor, substantially a La Cierva rotor with feathering control analogous to the Wilford control is mentioned here merely for purposes of classification, and will be taken up later under the discussion of direct control.

Stability of the Cierva Rotor.

There is one other element of superiority which the Cierva flapping rotor has over the fixed wing, and that is its inherent stability, both longitudinal and lateral. The discussion of this inherent stability would lead us too far afield, but both theory and wind tunnel experiments indicate that

if the rotor is displaced from its normal plane of rotation, the resultant thrust tends to restore equilibrium. This makes the flapping blade rotor particularly attractive for use in the helicopter.

2. Performance of the Autogiro as Compared with that of the Airplane.

The theoretical analyses of the rotor, with its varied motions and its mixture of dynamics and aerodynamics, is highly complex, and is invariably based on a number of assumptions and simplifications to make the mathematics tractable. As a result one has the feeling that no theoretical treatment is entirely reliable. The wind tunnel experimentation is scanty and not free from serious objections. As a result, in spite of numerous studies and publications no definite evaluation of the aerodynamic efficiency of the windmill rotor has as yet been made.

There is extreme divergence of views as regards efficiency.

On the one hand we have the sincere view held by many competent engineers that the autogiro with its many excellent characteristics at the low speed end of the range, holds out no hope of aerodynamic efficiency, of economy in cruising or of really high speed. In support of this view, such engineers argue that the equivalent flat plate or parasite area for a given gross weight is much higher than that of the airplane; that the aspect ratio of the blade disk area considered as a whole is very low; that there is interference between blades; that certain portions of the blades are always ineffective and merely drag producing; that all portions of the blade are ineffective at some point of the cycle; that blades at some point of the cycle work at a large angle of yaw to their span; that the mere existence of changing fields of flow is a cause of inefficiency; that skin friction effects must be pronounced since the blades always have a velocity considerably higher than the forward speed; that the parasite drag is always increased because the fuselage is affected by the downwash of the rotor; that the maximum Lift/Drag ratio of the rotor is of the order of 9 to 10, while the maximum Lift/Drag ratio of the fixed wing is now of the order of 20 or more; that no giro ever built even approaches the speed performance of an airplane of the same weight per horse-power.

On the other hand some exponents of the autogiro, not engaged in its industrial development, voice the most optimistic views as to attainable speed range, the high speeds ultimately possible, etc.

A really serious comparative study would be a work of magnitude and difficulty, but it seems safe to say that, as is not infrequently the case, the truth lies between these two extremes as the following general observations seem to indicate:

Comparison of Parasite Drags.

There is no reason why the parasite or equivalent drag area of the autogiro should be much higher than that of the moderate-sized single-engined airplane. The exposed struts of the early autogiros have given away to a short, well streamlined pylon bending gently with the fuselage. The fuselage of the autogiro may be just as well streamlined as that of the airplane. The larger, wider landing gear with higher shock absorber travel of the autogiro is partially compensated for by the smaller tail surfaces required.

Comparison of Machines Built for Very High Speed.

If landing speeds were disregarded, or rather if the stall speeds of airplane and giro were the same, then conceivably we could use a rotor of very small diameter, very heavily loaded per square foot of blade area, and per square foot of disk area. The total area of the blades would then be much smaller than the area of the airplane wing. The maintenance of autorotation would, at high speeds, be a serious problem; vibration effects—which may be roughly said to vary as the square of the rotational speeds—would be very serious; excessive coning would be a difficult thing to avoid. But what would be the situation in regard to high speed, if these difficulties could be overcome? Induced drag could be neglected in the comparison for the airplane because very little drag due to lift is created at high speeds, for the rotor because the blade disk area as a whole is working at high speed, and the blades themselves are working at higher speeds still, so that again induced drag effects are minimized. Then we should have to balance the profile drag of the larger

area of the airplane against the profile drag of the smaller blade area of the giro with the blades moving with a greater resultant speed. Interference effects would be slight. It would not be surprising if in this hypothetical condition there should be little speed superiority with the airplane were it not for one phenomenon, "compressibility burble," due to the effects of speeds approaching those of sound. There is for the moment a limitation to the possible speeds of the airplane because when flight speeds of say 500 miles are reached, local speeds over the upper surface of the airfoil approach or surpass the speed of sound with shock waves decreasing lift and increasing drag enormously. In the rapidly rotating blades of the giro this effect and the limitations to high speed would be still more pronounced. To disregard landing speed, to force the giro into an imitation of the very high speed airplane would be an enterprise very unlikely of success.

Comparison with an Airplane Built for Very Slow Speed.

Now let us turn to a converse situation, and consider what would happen if we attempted to build fixed-wing aircraft which should have the minimum flying speed of the airplane. Even with the lowest solidity ratio, i.e. ratio of blade area to disk area, ever attempted, namely .045 as on the Hafner gyroplane, we may still expect a maximum lift coefficient of say .8 based on the swept-out disk area. For the flapped and slotted wing we could expect a lift coefficient of 2.4. Let us take a rotor of 40 ft. diameter, and a disk area of 1,256 square feet for a machine of say 2,400 lbs, the airplane would then have to have an area of $\frac{1{,}256 \times .8}{2.4}$, that is 418 square feet and a loading per square foot of only 5.7 lbs. We know from general aeronautical experience that an airplane of this large wing area and low weight would be of excessive overall dimensions, very slow, poor in control at low speeds, and scarcely utilizable.

Of course the above analysis is crude and elementary. Nevertheless the indications are that if we essayed to build an airplane having the minimum speed characteristics of the autogiro, it would be a highly impractical affair.

Comparison of Machines of Moderate Power Suitable for Private Flying.

The most interesting comparison of all to be made, however, is between the autogiro with a minimum speed of round 20 miles/hour to be used by the private owner and the airplane of the small class with a minimum speed of something like 50 miles per hour. Before making such a comparison it is necessary to review the aerodynamic characteristics of the modern autogiro rotor.

The autogiro rotor began its career with four blades, a high solidity ratio of about .1, wide blades, a low loading per square foot of blade area. The large blade area was considered to be necessary to secure large values of the maximum lift coefficient and low landing speeds, and did indeed attain large values of maximum lift coefficient. But the drag was apt to be high. Later it was discovered that by reducing the solidity ratio while maintaining the same disk loading, rotor diameter and blade setting, the drag could be reduced while the maximum lift coefficient was not decreased to anything like the same extent. Therefore decrease in solidity was a step towards greater efficiency. Also in the giro rotor the maximum Lift/Drag ratio occurs at a much smaller fraction of the maximum lift coefficient; then and therefore in attempting to secure high speed, it is advisable and possible to load the giro rotor in such fashion that high speed and maximum Lift/Drag almost coincide, and that the angle of attack is not much greater than that required for autorotation. Again the maximum L/D occurs at a practically constant value of the ratio of forward speed to tip speed. Also the giro, loaded more heavily in relation to blade area, rotates more rapidly, and at maximum L/D its forward speed must be greater to maintain the appropriate ratio of forward speed to tip speed. Hence the giro rotor of lower solidity is more suitable to high speed work. The maximum L/D of the giro rotor is about ten, the L/D of the airplane wing flying at small angles is of the same order of magnitude. Therefore the designer of a giro could if he wished make the speed practically equal to that of an airplane of equal power and weight.

But since the L/D having passed its maximum value diminishes, the cruising efficiency would suffer badly and

compare unfavorably with the cruising efficiency of an airplane whose wing might have a maximum L/D of round twenty.

Therefore the autogiro designer cannot seek high speed alone neglecting cruising efficiency.

Any giro enthusiast who asserts that its speed can approach the speed of an efficient private airplane of equal weight and power, must be losing sight of the fact that cruising efficiency must not be entirely lost.

If flight were undertaken at altitudes with an autogiro, the comparison would be still more unfavorable. At altitudes, with supercharged engine, the whole secret of the higher speed attainable with the airplane is that it then flies at a higher lift, a higher angle of attack and is closer to functioning at top speed and best L/D. The giro at altitude would pass to a region where its plane of rotation is at a fairly high angle of attack to the forward wind stream, so that its drag is high and its L/D low. The autogiro seems quite unsuited for altitude work.

Where the real advantage of the giro lies is in the attainment of a very large speed range, because even if cruising efficiency is taken into account, it can function with its enormous equivalent lifting area in the blade disk at a reasonable L/D, when its lift coefficient is only a very small fraction of the maximum lift coefficient. The airplane cannot fly at the same fractional values of its maximum lift coefficient unless it has terrific speed and enormous power. The great point to stress in favor of the giro is this ability to secure a speed range of 6 to 1 and more, while the private airplane of moderate power even when flapped and slotted cannot do much better than $3\frac{1}{2}$.

Possibilities of Improvement.

It should also be pointed out that an enormous amount of research has made the fixed wing efficient. The giro rotor has been barely investigated in the laboratories. The aerodynamic research in solidity, plan form, taper, possible overdriving of the rotor with a small amount of power, maintenance of autorotation with very high speed r.p.m., variation in area of blades for varying conditions of flight, or even variation in blade diameter has scarcely begun. It took the

fixed airfoil nearly twenty years to advance from an L/D of ten to an L/D of twenty. The giro has advanced from a ratio of 6 to a ratio of 10 in perhaps seven or eight years, and it would be foolish to imagine that no further improvement is possible.

3. Control Systems.

Autogiro Direct Control.

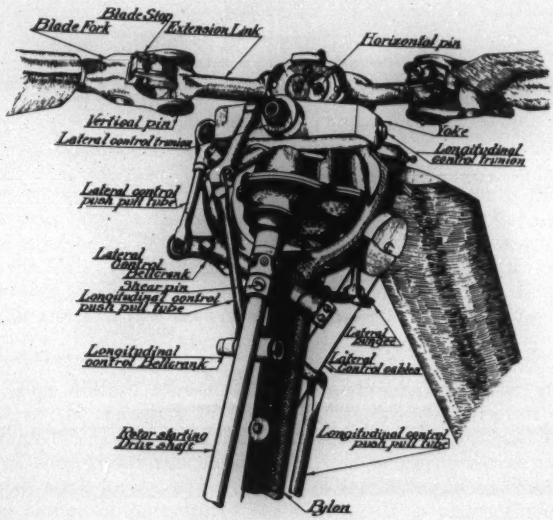
When the autogiro first appeared on the scene, it was provided with a fixed wing, almost wholly because lateral control had to be provided and the only way in which lateral control could be achieved was by the use of the conventional ailerons. A fixed wing there had to be even though the combination of fixed wing and autogiro rotor is indefensible from the point of view of aerodynamic efficiency. Again in early examples of the autogiro, a conventional rudder and elevator at the rear end of the fuselage had to be provided. It is a demonstration both of Cierva's genius and of his continuous interest in giro improvement, that from his mind came the idea of direct control of the rotor, which eliminated at one step the fixed wing, the ailerons elevator and, to all practical purposes, the rudder. This idea, simple as most valuable ideas, involved tilting the rotor axis.

The mechanism of the direct control is shown diagrammatically in Fig. III-7. The sketch is of interest as showing in general the essential elements of an autogiro rotor system. Each of the three blades have blade forks which are mounted on a vertical pin, with provision for limited and damped motion. Through an extension link the blades are given freedom about horizontal pins. The central hub is mounted on fore-and-aft and lateral trunnions in a yoke by means of which the position of the rotor axis can be changed to give the required lateral and directional control. The hub consists essentially of an axle which comprises within its structure the horizontal blade pivots and a hub case. The hub case carries the main rotor hub bearings, and the spiral bevel ring gear and pinion of the rotor starter. A simple push-pull system connects the yoke-trunnion system with the pilot's stick in the cockpit. A more detailed study of the mechanism indicates a marvel of mechanical ingenuity and effectiveness which is of great credit to Pitcairn and Kellett engineers, and to

engineers of mechanical engineering companies associated with this development work.

The principles of direct control operation are illustrated very clearly in the diagram of Fig. III-8. While as stated previously the lift of the rotor does not pass exactly through the rotor axis, it is sufficiently close for these diagrams to represent truly the action of direct control.

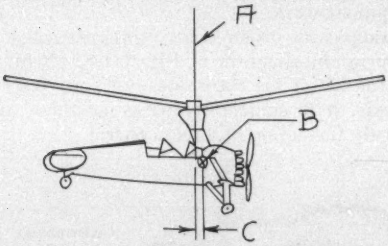
FIG. III-7.



Kellett direct control mechanism.

In the first of these diagrams normal flight is represented with the resultant force through the rotor producing a nosing down moment just sufficient to balance the contrary moment about the center of gravity produced by the rotor drag. In the second diagram, the rotor is tilted aft so that its moment area about the center of gravity is reduced and the aircraft is put into a nose-up or climbing attitude. Similarly in the third diagram, by tilting forward of the rotor a gliding attitude

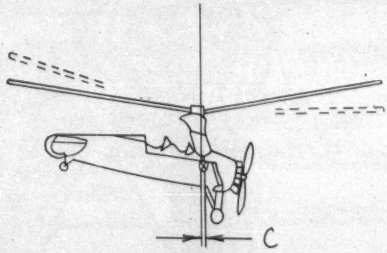
FIG. III-8.



Direct control operation of the autogiro.

1. Position of autogiro in level flight. A. Resultant force through rotor axis. B. Center of gravity. Relation of "A" to "B" is moment arm C required for proper balance.

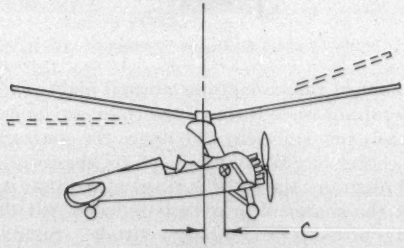
FIG. III-8.



Direct control operation of the autogiro.

2. Autogiro shown as control stick is moved aft. Moment arm "C" reduced causing ship to assume climbing attitude to reestablish correct relationship.

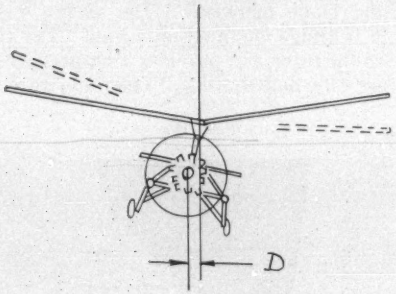
FIG. III-8.



Direct control operation of the autogiro.

3. Autogiro shown as control stick is moved forward. Moment arm "C" increased causing ship to assume diving attitude to reestablish correct relationship.

FIG. III-8.



Direct control operation of the autogiro.

4. Autogiro shown as control stick is moved to right causing moment arm "D."

can be assumed. In the fourth diagram, the rotor is tilted laterally and the thrust along the rotor axis then acts to put the machine in a banked attitude, and also to skid the machine to the lift. The skid imposes a side wind on the vertical tail surfaces tending to yaw the machine, and the combination of bank and yaw produces circling flight.

Wilford Direct Control.

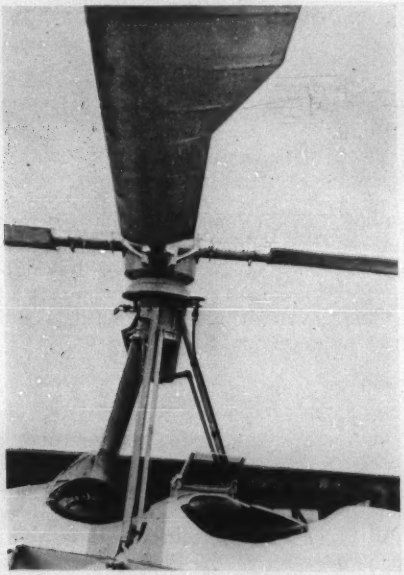
The Wilford Direct Control, as stated previously, grew out of the necessity of improving autorotation, but it developed as a highly powerful control system of equal effectiveness throughout the flight range. It needs moreover very small stick forces, since its axis of feathering is so close to the center of pressure of the airfoil. It is also indirectly valuable as a precursor of the Hafner control, and for its possibilities in application to the autogiro rotor and the helicopter airscrew.

The Wilford gyroplane and control are shown in the photograph of Fig. III-9 and in the diagram of Fig. III-10, which has been elucidated by Wheatley in the following terms:

"When the control is set for zero feathering, the instantaneous pitch of all the blades is equal to the pitch setting throughout an entire revolution. When feathering is intro-

duced the pitch of the advancing blade is decreased and of the retreating blade increased. The shafts *A* and *B* are supported in bearings mounted on a hub. The tube *C* does not turn with the rotor, but provides a support for *D*, which is the inner race of a ball bearing. The outer race *E* revolves

FIG. III-9.

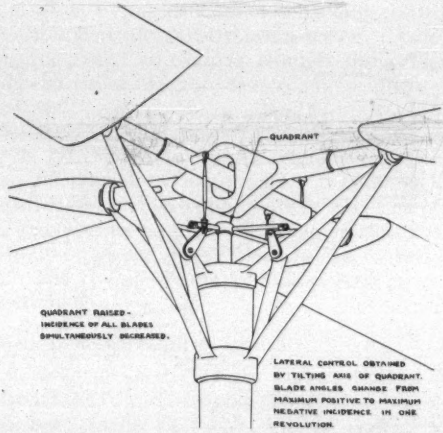


Wilford direct control.

with the rotor. The control shaft *F* can be turned by means of a hand crank, thereby raising rod *G* so that it is connected to *D*. This motion tilts the ball bearing about the pivots *H*. The two pins *I* extend into *E* and the arms *J* rotate the outer race *E* of the bearing. A sleeve (not shown in the figure) supports the two shafts *K* in bearings. The sleeve also supports the hub and, in turn, the shafts *A* and *B*. When

the bearing $D - E$ is tilted, the pins I rise and fall with respect to the shafts K as the rotor turns. The shafts K being held in bearings, an oscillation is imparted to arms L and, in turn, to the arms M that oscillate the shafts A and B. By means of this feathering of the blades rolling moments can

FIG. III-10.


QUADRANT
QUADRANT RAISED - INCIDENCE OF ALL BLADES SIMULTANEOUSLY DECREASED.
LATERAL CONTROL OBTAINED BY TILTING AXIS OF QUADRANT. BLADE ANGLES CHANGE FROM MAXIMUM POSITIVE TO MAXIMUM NEGATIVE INCIDENCE IN ONE REVOLUTION.

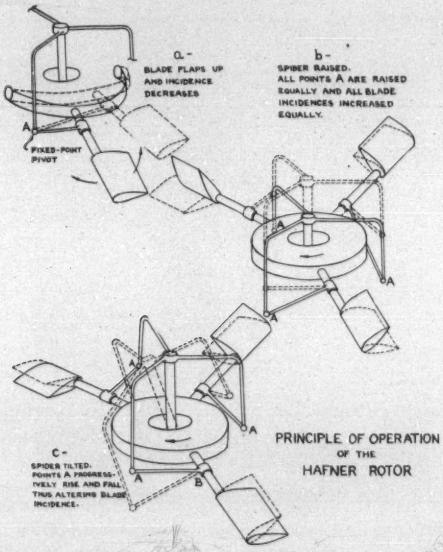
be controlled or imposed, and by tilting the bearing $D - E$ about another axis, pitching moment control is obtained."

Hafner Direct Control.

An autorotative type of aircraft, the Hafner, has attracted considerable attention in England and embodies another type of direct control (that is one in which elevators and ailerons are dispensed with) of great interest. Raoul Hafner, an Austrian by birth, now living in England, began by constructing a three-bladed single screw helicopter, with vertical fins in the slipstream of the rotor to counteract the torque, but soon passed to the study of the windmill rotor. His rotor is based on the same principle as that of Cierva since it embodies flapping blades with free rotation about a central axis. But as can be seen from Fig. III-11 there are differences

in the way in which the conception is carried out. Six radial flapping hinge bolts carry the yokes to which the blades are attached. These are interlapped in such a way that the hinge axes intersect the rotor axis and each other at the focal point. One difference between Cierva and Hafner is that the hub of the Hafner rotor rotates about a rigid axle through which all the loads are carried direct to the fuselage. Another

FIG. III-11.



difference lies in the fact that some feathering is combined with the flapping. But the main difference is found in the control, which is achieved by changing the angles of incidence or feathering the blades.

The three diagrams of Fig. III-11 illustrate the operation of the Hafner rotor in somewhat over-simplified fashion.

Diagram *a* indicates why the flapping is accompanied by some slight feathering. As the blade flaps upward the arm

attached to the fixed-point pivot causes the incidence to be diminished. Thus equalization of lift is accomplished by a combination of La Cierva flapping and Wilford feathering.

For changing the angle of incidence of the blades, there is a "spider" which rotates with the blades, and is mounted on a spindle universally pivoted on a spherical bearing lying at the focal point and carried by a pitch control piston. The spindle is tilted by movements of a hanging control column which is also spherically pivoted in the piston. As in Diagram 6, sliding the piston up or down changes the incidence of all the blades an equal amount, as is required in the process of direct take-off.

Movements of the control column and tilting of the spindle in turn tilts the spider which changes the blade incidence differentially (Diagram *C*). If blade incidence can be changed differentially fore-and-aft in the plane of rotation, there is longitudinal control. If blade incidence is changed differentially on either side of the fuselage, lateral control is secured. Mr. Hafner claims for this control great lightness and sensitivity.

Wilford Control in Application to Flapping Blades.

It has been claimed that the Hafner control derives in reality from the Wilford feathering control, and the suggestion has also been made that the Wilford control should be suitably modified to fit the La Cierva rotor, which would certainly be an interesting experiment.

4. Vibration.

In a classical paper before the Royal Aeronautical Society, Cierva stresses the very large number of secondary problems involved in the development of the autogiro and states that perhaps the most irritating of the secondary difficulties have been those of a dynamical nature vibratory in character. The fundamental dissymmetry of speeds on both sides of the rotor produces periodical variations in the lift, drag, lift and drag moments on each blade. The flapping hinges correct the dissymmetry of the lift moments so far as their average value at any rate. The vertical hinge permitting the blades a certain angular freedom relative to one

another allows for dissymmetry of drag moments. But while the flapping motion is strongly damped, there is no appreciable damping of the horizontal oscillations. These horizontal oscillations produced an irregular circular rocking motion known as "wobbling" which was only partially met by elastic interconnections between the blades. The correct solution was introduced by effecting the damping in the relative angular motion, between each blade and the hub. This suppressed free oscillations, as well as resonance in the horizontal oscillation of the blades. But great care still has to be exercised to avoid troublesome dynamical effects.

Similarly in the structural design of the blades, while the bending moment at the root is zero, and while the distribution of aerodynamic forces along the blade is well understood, there are inertia effects which are absent in the structural analysis of the fixed wing, so that the structural analysis of the giro blade is a much more subtle matter.

5. Direct Take-Off Giro.

de la Cierva Jump Take-Off.

Many advances have been made in the landing of airplanes with the aid of slots and flaps of various types. But in the take-off slots and flaps are of comparatively little utility because depression of the flap combines a useful increase in lift with an unfortunate increase in drag. The autogiro surpasses any airplane, whatever its slots and flaps, in its remarkably short landing run, steep glide or almost vertical descent. In the take-off the run of the autogiro is probably as short if not shorter than that of any airplane, but the subsequent climb is no steeper than that of any airplane, and for the most part much slower when measured in so many feet per minute of height attained. But the tireless imagination of de la Cierva and the rare ability of Agnew Larsen and R. H. Prewitt have given us the Direct Take-Off Autogiro which reduces the take-off run to zero feet, and in its subsequent motion approximates the achievement of the helicopter, without the complexity of the latter type.

As stated previously, each blade of the rotor has two degrees of freedom (in addition of course to the rotation about the main vertical axis). The blade is free to swing about an

inner horizontal pin, and also has an angular movement of a very few degrees of freedom about a vertical pin placed a little further out from the center of the rotor. All that was needed to achieve Direct Take-Off was to incline the vertical pin a few degrees outward from the main axis as shown in Fig. III-12. It is quite easy to understand the effectiveness of this ingenious idea.

FIG. III-12.

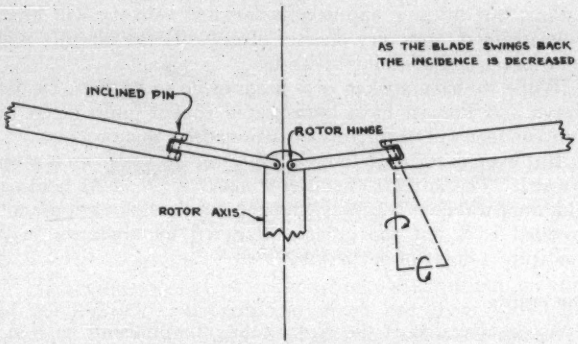


Diagram showing the effect of the inclined pin in direct take-off of the autogiro.

Let us suppose that the autogiro is at rest on the ground with the rotor brought up to speed in the usual way by shafting and gearing from the engine. Owing first to the inertia of the blades and later due to their drag the blades tend to lag behind the hub. With the vertical pin inclined outwards, a backward swing about the pin also tends to decrease the angle of incidence. With the blades decreased in incidence, and therefore in the position of minimum drag, they can be readily driven up to a speed some 25 per cent. greater than their normal r.p.m. Now let us imagine that the clutch is thrown out so that the motor is no longer driving the rotor. The inertia stored in the blades now tends to drive them ahead of the rotor hub and their incidence is now increased—the converse of what occurred in starting up. The blades are therefore now rotating at over-speed while at

a relatively large angle of incidence. Naturally a powerful lift is generated, greater than the weight of the machine.

If at the same time the engine is driving the propeller which develops forward thrust, the whole machine rises on a steep, almost vertical path. This practically vertical climb goes on until a height of some 20 to 30 feet is reached. By that time the excess kinetic energy of the blades will have been consumed, and they will have taken up their normal attitude. The path of the giro in space will sink for an instant, but by now appreciable forward velocity will have been attained, and very shortly afterwards the aircraft will be in its normal climbing attitude.

While we have spoken of a jump of 20 to 30 feet, De La Cierva and Prewitt have both stated that a jump of 60 or even 100 feet will ultimately be attained by this process.

But even a 20 to 30 foot direct jump is an immense step forward. The autogiro no longer needs a prepared landing field, mud will be no obstacle and the smallest plot of ground, provided it is not too greatly hindered by obstacles, will constitute a point of departure.

Hafner Towering.

A consideration of the direct take-off would not be complete without stating Mr. Hafner's argument regarding the process of energy assisted take-off. In the La Cierva jump-off, as we have seen, the process is automatic with a rather large initial acceleration, and a subsequent loss of attitude. In the Hafner machine, blade incidence is at all times under control of the pilot, and the process of assisted take-off passes is claimed to be a smoother one, and is characterized as "towering" (Fig. III-13). The rotor is set to the no-lift angle, and the rotor clutch is brought gradually into engagement. "When the rotor reaches the required rotational speed in excess of that of autorotation, the throttle is fully opened, the clutch automatically slipping to permit this, and the pilot grips the pitch control lever, thus releasing the trip of the clutch. He then eases the lift lever backwards, feeling the machine into the air. The period over which the control is operated varies with the prevailing wind conditions, being shorter when the wind enables flying speed to be reached more

rapidly, and the machine towers steeply into the air; or it may be extended about four seconds, enabling the machine . . . to take-off even in still air with no forward run. It will be noticed . . . that the machine climbs directly forward and upward."

It is clear however that the Cierva jump will eventually be smoother, and the automatic character of a maneuver is always agreeable to a pilot.

FIG. III-13.

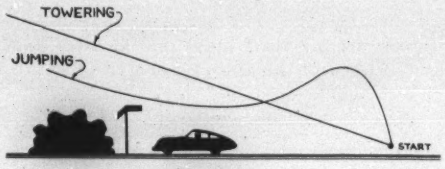


Diagram showing the advantage of a steady climb or "towering" take-off as obtained by a controlled change of pitch.

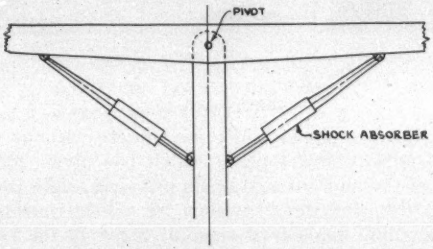
6. Herrick Convertoplane.

This paper would be sadly incomplete without mention of the Herrick Convertoplane which has given convincing evidence of the high interest of its principle while the simple fixed airfoil is, and should remain for a long time the most efficient medium for heavier-than-air flight, at the lower end of the scale the fixed wing machine or airplane leaves something to be desired.

Gerard P. Herrick's simple conception, and all engineering conceptions of value are apt to be simple, is that a craft might be created which in normal flight would depend on a fixed wing, and embody all the advantages of a fixed wing, but in emergencies or for landing in restricted territory would be convertible to a rotary system and embrace all the advantages of the autogiro or gyroplane. This interesting new principle is illustrated diagrammatically in Fig. III-14 and the machine itself is shown in the photograph of Fig. III-15. The upper and larger wing of a more or less conventional biplane is provided with an airfoil which is symmetrical fore-and-aft and of the character indicated in this diagram. The upper wing is mounted on a substantially horizontal

hinge at its center, about which it is eventually free to rotate or oscillate within certain limits. The horizontal hinge is in turn supported by a vertical shaft or strut in such fashion that the wing may after suitable release be free to revolve about a vertical axis. When the convertoplane is flying as a normal biplane, the upper wing is prevented from rotation by two struts extending from the top of the fuselage cockpit. When the struts are released; an electric starter applies an initial turning moment to the vertical shaft. The upper wing set into rotation and free to oscillate, within certain limits, then rapidly assumes the character of an autorotative system, and the novel aircraft then takes on the slow landing and other characteristics of the autogiro or gyroplane.

FIG. III-14.



Schematic diagram of Herrick convertoplane rotor.
Oscillation of ± 10°. ± 3° by-passed movement. ± oscillation will produce 5¼″ shock absorber movement.

To discuss the convertoplane in detail would be the task of another paper. Nor is it yet clearly established that its theoretically desirable characteristics of enhanced safety and what we may term its parachutal qualities are such as to compensate for some degree of complexity added to the airplane; nor that it will rapidly receive commercial applications. But on the other hand, the convertoplane deserves the serious consideration of everyone interested in rotary aircraft, and to the credit of Mr. Herrick's energy, persistence and self-sacrifice the following solid achievements definitely stand:

a. The development of a special, fore-and-aft symmetrical

airfoil which, as a long series of wind tunnel tests indicate, has almost the efficiency of the conventional tapered trailing edge airfoil. The necessity of such an airfoil is apparent when it is considered that it must at one time act as a fixed airfoil, while at another time the normal leading edge advancing in rotational motion must encounter a resultant airstream in suitable fashion, and at the same time the normal trailing edge

FIG. III-15.

Herrick convertoplane.

retreating in rotational motion must encounter the resultant airstream and retain reasonable lift and efficiency properties.

b. The development of a rotor system, with freedom about a horizontal hinge, and rotation about a substantially vertical axis, which has the autorotative properties, the high lift and the moderate efficiency of the autogiro or gyroplane rotor. This conclusion also is drawn from tests in the tunnel in which the writer has been privileged to participate.

c. Normal and in every way satisfactory flight as a biplane, with repeated conversions in the air to the rotary system and

subsequent slow landings. The machine which has undergone these tests in Philadelphia is indicated in the photograph of Fig. III-15. In the conversion in flight there is a noteworthy difficulty. In the very first stages of the conversion, before the truly autorotative condition has been reached and the continuous blade has assumed its appropriate oscillatory motion about the horizontal hinge, the advancing blade experiences a greater velocity than the retreating blade tip on the other side of the wing, and consequently produces more lift, and hence disturbing rolling and yawing moments are imposed on the aircraft. There is every reason to believe that this difficulty has been met partly by the provision of the hydraulic shock absorbers previously mentioned, partly by the fact that the pilot can intelligently and readily anticipate the disturbing motions by actuation of rudder or ailerons or both.

7. The Roadable Autogiro.

One of the greatest handicaps to the expansion of private flying is the difficulty of getting to and from the airports, which in many cases are difficult of access. Accordingly the suggestion of an airplane capable of road travel has been made many times, and as far back as 1921, Réné Tampier successfully flew his "avion-automobile" and then surprized the people of Paris by driving his craft, wings folded back, tail first through the streets of Paris. More recently a similar attempt at an airplane automobile has been made in the United States in the form of the Waterman Aeromobile. The possibility of a roadable direct take-off autogiro is of course even more tempting, since with its wonderful landing and take-off properties it can make use of a far smaller field than even the smallest airport. It was entirely logical therefore that the Department of Commerce should sponsor, and the Pitcairn Autogiro Company should develop a roadable autogiro, designed by Agnew Larsen, its chief engineer, with Mr. Stanley as his associate. A general view of the Roadable Autogiro, equipped with a 90 horsepower, seven-cylinder air-cooled Pobjoy engine, and an enclosed cabin with two occupants, is shown in Fig. III-16. Rotor blades were designed which could be readily folded back over the fuselage and fastened down to the tail surfaces. The engine was placed in

back of the two-seater enclosed cabin and provided with a long transmission shaft and clutch to the forward propeller, and a drive to the rear driving wheel through a conventional clutch and bevel gearing. When the vehicle was operated as an automobile the propeller was disconnected by a dog clutch and locked in a vertical position so that it should not be rotated by wind velocity. Minimum speed in the air was about 20 m.p.h., top speed on the road was 25 m.p.h. and maximum speed in the air with an 85 hp. Pobjoy engine was approximately 90 m.p.h. Take-off was in less than 150 feet, range $3\frac{1}{2}$

FIG. III-16.

The Pitcairn roadable autogiro.

hours with two occupants and 40 lbs. of baggage. The machine had an overall length of 24 feet, with its 17 foot blades folded back, and proved entirely manageable in traffic. Additional complexity and weight of the ground drive were no bar to the passing of tests and the attainment of successful flying characteristics.

The development is significant in itself, and also most gratifying because it indicates that American engineers will forge ahead, even in the absence of the guiding genius of De La Cierva.

(*Continued in next issue.*)

Unique Steel Making Laboratory.—(*Manufacturers' Record*, Vol. CVII, No. 10.) Through use of a miniature steel plant, the first of its kind in the steel industry, a unique approach to research is being made in the new research and development laboratory of the Jones & Laughlin Steel Corporation, Pittsburgh. Here, steel making facilities such as an open hearth furnace, heat treating furnaces and rolling mills of pilot plant size are used in conjunction with extensively equipped chemical, physical and metallographic laboratories in a direct approach to solving the problems of steel quality. This overcomes the handicap established in the past when it has been the general practice to conduct research by a laboratory procedure which resulted in advancements being made faster than they could be tested and applied in the mills. A feature of the equipment in the new laboratory is a small open hearth furnace, which is recuperative, having a capacity of 1500 pounds. There is installed, in connection with this, an unusual type burner. Ingots cast weigh from 185 to 900 pounds as compared with ingots from commercial production which weigh 3½ tons to 10 tons. There is also provided a 375 pound electric arc furnace used for experiments on slag and steel making, and a 30 pound electric induction furnace which affords the most exacting control over experimental steel making. A cupola is available to supply molten iron for a small Bessemer converter which will be constructed later. Two rolling mills are used in the laboratory, one for primary reduction of ingots and the other for further reducing the bars into convenient sizes for test specimens.

R. H. O.

THE VELOCITY OF SOUND.

BY

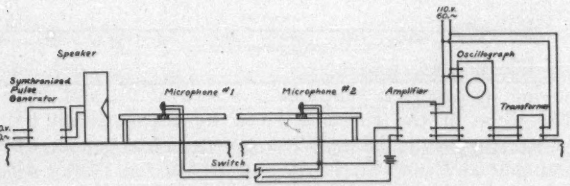
R. C. COLWELL, Ph.D., A. W. FRIEND, M.S., and D. A. McGRAW, M.S.,

Department of Physics, West Virginia University

A previous publication [1] gave results of a determination of the velocity of sound by an oscillographic method. The method involved propagation of sixty evenly spaced sound wave pulses per second each with a sharp pressure peak. The signal was picked up on a microphone and applied to the vertical plates of an oscillograph; by synchronizing with a 60 cycle horizontal sweep voltage, a standing image of the signal was produced on the screen. Measurements were taken by moving the microphone along a rail until the pulse image had described a complete cycle. Thus the product of 60 times the distance through which the microphone moved gave the velocity of sound at the prevailing temperature.

The original apparatus has since been improved by the addition of a second microphone; one is placed at each end of the rail (Fig. 1), and the two connected in parallel through

FIG. 1.



a double-throw switch. This allows the two positions to be located by separate microphones, eliminating the necessity of sliding one microphone the entire length of the rail. Also, by picking up the signal at the two points alternately, it is

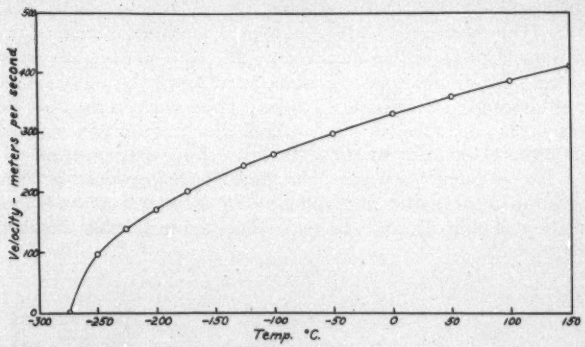
[1] R. C. Colwell, A. W. Friend and D. A. McGraw, J. FRANK. INST., 225, 579 (1938).

possible to adjust the pulses such that both peaks appear on the same reference line. The interchange insures balance by minimizing the possibility of error due to a pulse shift during the time of measurement.

Determinations were made over a range from 2.5° C. to 29.6° C. The average of all previous determinations gave 331.57 meters per second for the velocity at 0° C., comparing closely with the accepted values.

An analysis of the equation $V_t = V_0\sqrt{1 + t/273}$, where V_0 is the velocity at zero, and V_t is the velocity at the observed temperature t in degrees C. shows that, if V_t is plotted as a function of t, the resulting curve (Fig. 2) will be a parabola,

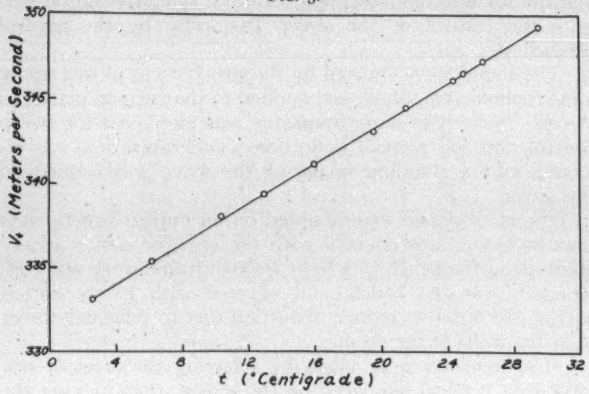
FIG. 2.



having its origin at the point $t = -273°$ C., and $V_t = 0$. The slope of the curve is given by the equation $dV_t/dt = V_0^2/2(273)V_t$. Taking $V_0 = 331.57$ meters per second we find that at $t = 0°$ C., $dV_t/dt = 0.607$; at $t = 15°$ C., $dV_t/dt = 0.592$; and at $t = 30°$ C., $dV_t/dt = 0.586$. Hence within the interval over which the measurements were taken, the slope is so nearly constant that the curve may be regarded as a straight line with an average slope of 0.595 meter per second per degree.

Plotting the measured values of V_t against t gives the straight line of Fig. 3. The slope is estimated to be 0.60

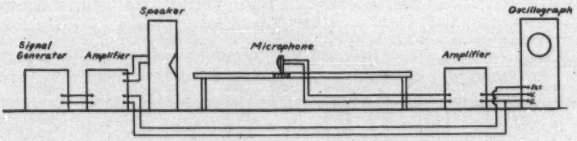
FIG. 3.



meter per second per degree, in good agreement with the average value given above.

An alternative method has been devised by which it is possible to make accurate measurements over shorter distances. A schematic diagram of the apparatus used is shown is Fig. 4.

FIG. 4.



The sound sources employed were an electrically driven tuning fork of known frequency (1000) and a calibrated audio-oscillator; any type of oscillator which produces an audio frequency sine-wave voltage may be used.

The sinusoidal signal of the oscillator was applied to an amplifier, and the monitor terminals of the amplifier were connected to a speaker. The current from the output terminals of the amplifier was applied directly to the external sweep terminals of an oscillograph. Adjustment of the oscil-

lograph for internal sweep and external synchronization permits the control of the sweep frequency by the applied frequency.

The sound wave emitted by the speaker was picked up by a microphone, amplified, and applied to the vertical plates, as shown. Since the same frequency was employed for sweep control and for vertical deflection, synchronization was effected, and a standing image of the wave was formed on the screen.

The microphone was mounted on an optical bench such that its center was co-axial with the speaker center at any point along the bench. A light wooden frame-work was constructed over the bench, and covered with heavy cotton batting, in order to reduce distortion due to reflected waves from the walls of the room.

Measurements were taken by referring the crest of one wave to a vertical line ruled on the screen, then moving the microphone until the next successive wave crest coincided with the same line of reference; hence the distance moved by the microphone was equivalent to one wave-length of the transmitted sound wave.

The sine waves used were produced by a well known make of standard frequency generator. The calibration was obtained by means of Lissajou's figures on a cathode ray oscillo-

TABLE I.

Temp. ° C.....	23.2	26.0	23.2	26.0	21.6
Frequency.....	1760	1760	1320	1320	880
	19.5	19.6	26.3	26.3	39.0
	19.5	19.7	26.1	26.1	39.4
	19.6	19.4	26.4	26.3	39.2
	19.6	19.8	26.2	26.0	39.0
	19.4	19.5	26.1	26.4	39.2
	19.7	19.4	26.4	26.5	39.3
	19.6	19.6	26.2	26.4	39.3
	19.4	19.3	26.3	26.0	39.1
	19.6	19.7	26.5	26.6	38.9
	19.5	19.5	26.1	26.4	39.1
Average.....	19.52	19.55	26.26	26.30	39.15
V_t.....	343.55	344.08	346.63	347.16	344.52
V_0.....	329.83	328.79	332.79	331.73	331.59

TABLE II.

Temp. ° C.	21.6	26.0	24.0	25.6	30.0
Frequency	440	440	880	1000	1000
	78.1	78.8	39.4	34.6	35.2
	78.3	78.3	39.5	34.8	34.9
	78.3	78.4	39.2	34.5	35.1
	78.4	78.8	39.3	34.4	35.3
	78.2	78.6	39.2	34.7	34.9
	78.4	78.5	39.4	34.5	35.2
	78.2	78.6	39.5	34.8	34.9
	78.3	78.6	39.4	34.3	35.1
	78.1	78.3	39.3	34.7	35.0
	78.3	78.4	39.3	34.5	34.8
Average	78.26	78.53	39.35	34.58	35.04
V_t	344.34	345.53	346.28	345.80	350.40
V_0	331.42	330.19	332.00	330.06	332.76

Average V_0 = 331.12 meters per second.

scope screen with the use of standard signals transmitted from the National Bureau of Standards (Station WWV). Due to the accuracy of calibration it is believed that the errors introduced by inaccuracy of the frequency are unimportant.

Wave-lengths were measured at frequencies of 440, 880, 1000, 1320, and 1760 cycles per second. Two series of ten measurements were taken at each frequency. The average wave-length was determined for each series, and the velocity of sound at the observed temperature was calculated by the equation $V_t = n\lambda$. Correcting all values of V_t to 0° C. and averaging gave the value 331.12 meters per second for the velocity of sound at zero. The values of the measured wave-lengths and the calculated values of V_t and V_0 are listed in the accompanying tables.

Steam Heating in the Sky.—(*Heating, Piping and Air Conditioning*, Vol. 10, No. 10.) The new Douglas DC-4—"world's largest and most luxurious" commercial land plane—is heated by a steam heating system with cabin temperatures governed by a combination of automatic and manual control. General practice has usually been to control temperatures entirely by manual means (this being one of the duties of the stewardess) for vibration has affected control instruments so greatly as to make their use for aircraft service impractical. The new plane which is soon to be ready for service tests by five major air lines for which it was developed, will seat 42 passengers and a crew of five; as a sleeper it will accommodate 30, and includes such features as hot and cold running water, dressing rooms, and even a telephone system capable of connecting to any exchange. As the windows of a transport plane cannot be opened because of the engine noise that would be admitted, all ventilation must be through air ducts. There are really two independent heating systems on the DC-4, with one boiler connected to one radiator and each side functioning; this assures against complete heating failures, as each unit can do a fair job by itself. Steam radiators or fin coils are used in the ducts of sufficient capacity, capable of delivering over 400,000 B.t.u. per hour. Steam is supplied by two flash type water tube boilers, one in each of the two inboard engine exhausts. Each unit operates on seven quarts of water, with only about three quarts actually used. The system operates at about 24 lb. absolute. The cabin temperatures are controlled by mixing hot air, and cold air bypassed around the radiator, the dampers being governed by thermostat. Cooling the air is unnecessary in flight since the ship seldom if ever needs to fly in temperatures above the comfort range.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

TURBULENCE AND THE BOUNDARY LAYER.

Thirty-five years ago (on December 17, 1903) the first successful flights in a power-driven man-carrying airplane were made by Wilbur and Orville Wright. It has long been the custom of the Royal Aeronautical Society of Great Britain to commemorate this event by an annual Wilbur Wright Memorial Lecture and 26 such lectures have been delivered. In 1937 the much younger Institute of the Aeronautical Sciences in this country inaugurated a similar series of annual lectures called the Wright Brothers Lectures, the first of which was given by Professor B. Melvill Jones of Cambridge University, England. The second lecture in this series, at Columbia University, New York, on December 17, 1938, was delivered by Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division of the National Bureau of Standards, on the subject, "Turbulence and the Boundary Layer."

The successful flights of the Wright Brothers followed a series of well planned scientific investigations, first on kites and gliders in free flight (which showed the incorrectness of existing scientific data), and second on small models in the controlled air stream of a wind tunnel. Tests were made on about 200 models.

The wind tunnel has continued to be an indispensable tool of the aeronautical engineer. It has developed and improved along with the airplane. The ideal wind tunnel would reproduce exactly the relative motion between the air and the airplane, and hence the speed of its air stream should be uniform and constant. The air flow in early wind tunnels was very unsteady, but the design was improved until by about 1910 the flow was steady as determined by ordinary instruments. However, discrepancies were soon found between measurements in different wind tunnels, and these

* Communicated by the Director.

were traced to small irregularities in the motion of the air of a frequency too high to affect the instruments generally used. This irregular motion was called turbulence.

Systematic studies of the methods of measuring turbulence and its effect in wind tunnel measurements were begun about 10 years ago at the Bureau with the coöperation and financial assistance of the National Advisory Committee for Aeronautics. Apparatus was developed based on the hot wire anemometer for direct measurement of the intensity of the turbulence, and more recently for measuring its scale, i.e. the average size of the irregularly moving air masses. Some studies have been made and others are in progress on the effect of the intensity and scale of turbulence in wind tunnel measurements.

The fundamental effect of turbulence is to modify the flow of air very close to the surface of the body under study. Near the surface in the so-called boundary layer the speed of the air relative to the surface drops rapidly to zero. This boundary layer is very thin—a few hundredths of an inch in an ordinary model test in a wind tunnel. The flow within it may be of a smooth laminar type or of an eddying type. The location of the point of transition between the two types is dependent on the turbulence.

In his lecture, Doctor Dryden gave a general account of the work at the National Bureau of Standards on turbulence and the boundary layer, with particular attention to the most recent work. He pointed out that while the elements of the subject are now fairly well understood much additional experimental work will be required to complete the picture.

TURBULENCE AND DIFFUSION.

Chemical engineers are interested in the motion of fluids not only as a means of transporting materials in gaseous or liquid form or in suspension or solution, but also as a factor in many other physical processes used in the chemical industry, such as heat transfer and diffusion. In recognition of this interest, the Industrial and Engineering Division of the American Chemical Society organized a symposium on fluid dynamics which was held at the annual meeting of the division in Pittsburgh, December 27–28, 1938.

As a part of this symposium, a review of the experimental and theoretical aspects of turbulence in relation to the process of diffusion was presented by Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division of the Bureau. Turbulence, as explained in the preceding item, is an irregular random motion of fluids, changing rapidly with time at rates not detected by ordinary measuring instruments, which is superposed on the apparently steady motion in most cases of fluid flow of technical interest. The presence of turbulence profoundly affects the magnitude of the friction between the fluid and objects immersed in it, heat transfer, diffusion, mixing, dissolving, evaporation, etc.

The process of diffusion has been found very useful in the study of turbulence, and diffusion forms a suitable framework for setting forth the present state of knowledge of turbulence. Turbulence is now generally described in ways analogous to the concepts of the kinetic theory of gases, namely in terms of the root-mean-square velocity fluctuation and a linear dimension fixing the scale. Methods of measuring these statistical properties of turbulence in air streams are now available, and considerable progress has been made in the theory of turbulence by G. I. Taylor of Cambridge, England, and Th. von Kármán of Pasadena, California.

IMPROVED RADIOMETEOROGRAPH ON THE OLLAND PRINCIPLE.

In the January number of the *Journal of Research* (RP1169), L. F. Curtiss, A. V. Astin, L. L. Stockman, and B. W. Brown set forth the latest results which have been obtained at the Bureau with a radiometeorograph developed according to the Olland principle, with the coöperation of the U. S. Weather Bureau.

It is now recognized that the radiometeorograph (a small automatic radio device attached to a free rubber balloon, which, as it rises, sends back to earth a more or less continuous record of pressure, temperature, and humidity) is the only satisfactory way to secure this information. Plans are therefore being made by the U. S. Weather Bureau and other meteorological services to install radiometeorographs as rapidly as funds will permit.

The present paper deals with an Olland type instrument in which a rotary electric contactor is driven by a tiny electric motor weighing only 2 ounces and capable of running for several days from a single flashlight cell of the size used in "fountain pen" flashlights. As this rotary contact touches arms attached to pressure, temperature, and humidity elements, it keys a small radio transmitter which sends a signal back to earth. From the times between signals it is possible to know the pressure, temperature, and humidity at the height the balloon has attained at that instant. An automatic recording receiver is used at a ground station to make these determinations convenient and accurate.

In developing the instrument, special attention has been given to accuracy so that the pressure measurements are reliable to about 0.2 per cent., and the temperature measurements to 1 per cent. A humidity element, using goldbeaters' skin, gives humidity indications accurate to about 5 per cent.

A special advantage of the Olland system for radiometeorographs is that the radio transmitter is on only during the brief times when the rotating element and the indicating arms are in electrical contact. Thus the drain on the B batteries of the radio transmitter is very slight and lighter batteries can be used than otherwise would be necessary. At the same time this arrangement permits the use of a high signal current so that strong signals are emitted which are very easy to receive.

Tests of the equipment have been made by sending up instruments attached to balloons to altitudes of approximately 12 miles with thoroughly satisfactory results.

WATER PERMEABILITY OF MASONRY WALLS.

When exterior masonry walls of buildings allow dampness to penetrate to the interior, as occasionally happens when exposed to wind-driven rains, damage to the interior decorations may be sufficient to require their replacement. These repairs are costly and often additional expense is necessary in order to prevent recurrence of the damage. With the hope of securing useful information on the best methods of constructing walls resistant to rain penetration, the Bureau,

in coöperation with other governmental agencies, has investigated the water permeability of masonry walls. A full discussion of this work is now available as Building Material and Structures report BMS7, copies of which are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

Walls of brick, structural clay tile, and hollow concrete unit masonry were tested under conditions resembling exposures to wind and rain. Five kinds of workmanship (method of filling joints), three kinds of brick, six kinds of structural clay tile, two kinds of hollow concrete units, and six different mortars were used in the construction of the walls. One group consisting of 48 brick walls included specimens of three kinds of brick, four cement-lime mortars, and two classes of workmanship, constructed in all possible combinations. The walls of structural clay tile were either with stucco or with brick of a single variety. Those of concrete units were faced either with the same brick or with cement paint.

The effectiveness of several methods of "waterproofing" were compared by retesting some of the walls after they had been given waterproofing treatments. These included the filling of openings in the face joints with mortar, grout, or wax, and the application to the exposed surfaces of colorless solutions or paints. Most of the walls were subjected to water penetration tests under two different conditions. Water was applied near the tops of the walls in a manner to produce a thin film of water over their outside faces. In the "capillarity" test no pressure was applied to the exposed face, the water penetrating under the forces of capillarity and gravity only. In the "heavy-rain" test a static air pressure of 10 lb./ft.^{2} was maintained against the exposed face.

In the water penetration tests the performance of each wall depended more upon the quality of the workmanship than upon any other factor. Brick walls having the interior joints well filled with mortar usually were tight, whereas those with poorly filled joints leaked. The use of mortars of medium or high water retentivity, the wetting of absorptive brick before use, and the application of a parging of mortar on the back of the facing wythe all helped to make walls

more resistant to moisture penetration. Changes in the relative proportions of lime and cement in the mortars, the omission of two-thirds of the normal number of header brick, or the insertion of a limestone sill or belt course had no important effect on the permeability of the walls. On the average, when the joints were not well filled, walls with a brick facing and a backing of hollow masonry units were slightly less permeable than brick walls of equal thickness. With well filled joints the performance of walls with hollow units was somewhat superior to otherwise similar all-brick walls in the capillarity test but inferior in the heavy-rain test. The performance of walls of structural clay tile faced with portland cement stucco was somewhat better than the average for the brick walls. The filling of openings in the joints with mortar, grout, or wax was effective in stopping leakage. Colorless water-proofing solutions did not stop leakage through openings in the joints, but were effective in improving the performance of walls of absorptive brick when the openings in the joints had been sealed. Coatings of molten paraffin, oil paint, and cement paint were effective in reducing moisture penetration.

PERMEABILITY OF NEOPRENE TO GASES.

Because of its high degree of elastic extensibility rubber has long been employed as the gas-retaining film in the construction of a wide variety of inflated objects. However its comparatively high permeability limits its usefulness for many purposes, particularly in gas-containing structures in lighter-than-air craft. Neoprene is one of a group of modern synthetic integuments which is characterized by rubber-like elasticity. It differs from rubber in its superior resistance to swelling in oils and gasoline. A less generally known quality is its lower rate of permeation by gases. In view of the possible extensive use of this material in the construction of aeronautical fabrics, an investigation of its permeability was conducted at the Bureau for the Bureau of Aeronautics, United States Navy Department. The facts thus obtained are presented in a paper (RP1166) by Theron P. Sager and Max Sucher, in the January number of the *Journal of Research*.

The permeability of neoprene at 25° C. (77° F.) is shown to be about one-fifth to one-sixth that of rubber for films of equal thickness, and about one-third to one-fourth for those of equal weight, the difference being due to the higher specific gravity of neoprene as compared to rubber. The relative permeabilities of helium and carbon dioxide to that of hydrogen as unity are approximately the same as those of rubber. The increase in permeability with temperature is shown to be exponential.

The presence of cloth in neoprene-coated fabrics was found to contribute to the impedance to gases to the same extent as with rubberized fabrics. The presence of moderate amounts of the usual compounding ingredients does not appreciably affect the rate of permeation. While no advantage was gained from including paraffin wax in the coating composition, its employment as a supplementary coating on the fabric was shown to lower the permeability decidedly. Coatings spread with cements containing highly volatile solvents tend to have pinholes. Toluol, or its equivalent, appears to be the most satisfactory solvent.

SECOND SPECTRUM OF XENON.

In addition to its well known abundant constituents, the atmosphere contains five chemically inactive elements known as the noble gases. These are helium, neon, argon, krypton, and xenon. In the periodic chart of the elements they occupy the seventh column in the order given. Xenon is the heaviest and rarest of the group having a concentration of only 0.000009 per cent. of the atmosphere. Each of these gases emits a characteristic spectrum when contained in a Geissler tube at low pressure and made luminous by the passage of a high voltage current from the secondary of a transformer. The spectra obtained with this simple circuit are characterized by a moderate abundance of lines generally appearing in close groups such as the familiar red group in neon. These lines are very sharp and their wave-lengths can be measured with extreme precision. They have been found useful as spectroscopic standards of wave-length and in the calibration of gages. If the circuit is made disruptive by

introducing condensers and a spark gap, the discharge changes markedly in appearance becoming much more brilliant and changing in color. Examination by a spectroscope shows an almost entirely different spectrum with a much greater population of lines. The existence of these two entirely different types of xenon spectra was mentioned in the announcement of the discovery of the gas by Ramsey and Travers in 1898. We know now that spectra of the first mentioned type originate in atoms of their respective elements, whereas spectra accompanying disruptive condensed discharges are due to ions resulting from the removal of one or more of the electrons which make up the outer structure of the atoms.

The various spectra of the rare atmospheric gases have been the subject of numerous investigations at the Bureau. In 1928, C. J. Humphreys became associated with the work, collaborating in a series of investigations with Wm. F. Meggers and T. L. de Bruin. The spectra characteristic of rare gas ions are mainly of theoretical interest, most of the lines being insufficiently sharp to be considered as part of the system of standard wave-lengths. It is desirable, however, that such spectra be analyzed as far as possible; in other words, that as many of the lines be classified as transitions between known energy levels as a reasonable expenditure of time and labor will permit and that a satisfactory interpretation of these levels be reached. Concepts now prevalent of the structure of atoms are based for the most part on the information obtained from such analyses, and it is important that the evidence either for or against such concepts be made as complete as possible by investigating all spectra subject to experimental study. The spectra of noble gas ions also have properties peculiar to them as a class which make such studies of special importance. Thus, RP1164 in the January *Journal of Research* is concerned entirely with the second spectrum of xenon (Xe II) characteristic of once ionized xenon atoms (Xe^+). The spectra of neutral xenon (Xe I) and doubly ionized xenon (Xe III) have previously been reported, as have also the spectra of neutral, singly ionized, and doubly ionized krypton (Kr I, Kr II, and Kr III). Observations extending from 2,200 A in the ultraviolet to 10,200 A in the

infra have resulted in the compilation of a description of xenon spectra from condensed Geissler tube discharges containing estimates of intensity and wave-lengths of about 2,600 lines. From these the lines belonging to Xe II only were selected for publication in this paper. Such lines can be distinguished by the fact that they are relatively unaffected by inductance in the circuit; whereas, lines from ions formed by the removal of more than one electron are weakened in intensity. The published list contains 1,200 lines, of which 633 are classified as transitions between 103 levels. Observed levels are interpreted in accordance with the Hund theory of spectra as far as the evidence permits. Evidence from observed regularities indicates that the conspicuous sharp lines have been observed with such precision that the wave-lengths are consistent to 0.01 A or less, or about one part in 500,000 for the visible region.

SPECTRAL REFLECTIVITY OF RHODIUM.

The spectral reflectivity of rhodium in the ultraviolet and in the visible spectrum is described in RP1168 by W. W. Coblentz and R. Stair, in the *Journal of Research* for January. The samples examined consisted of mirrors of rhodium deposited electrolytically on plate glass and upon a highly polished surface of copper. The reflectivity of rhodium decreases rapidly with wave-length, to a low value in the ultraviolet. In the visible spectrum the reflectivity is somewhat higher than chromium and hence rhodium is more efficient as a reflecting surface.

Interferometers for Expansion Measurements.—Accuracies to 1/1,000,000 inch in measuring small displacements are attained with ease and dependabiilty by utilizing the interference of light waves. The interferometer method is the accepted standard for determination of thermal expansions at temperatures as high as 1000 deg. C. (1850 deg. F.) of ceramic materials, vitreous enamels and glasses, and is also useful for metals and many other substances. The same equipment with varied forms of the interferometer is used for measuring setting expansions of dental materials, for calibrating Hæmacytometers, for determination of flexures and other small motions or changes in length. The measurements give, with great accuracy, the change in the separation of two parallel quartz plates, as indicated by the motion of the interference fringes. In the thermal expansion interferometer, the upper interferometer plate rests upon three specimens placed between the plates. In the dental interferometer, the upper plate is supported at one point by the specimen and at two points by adjustable screws. By suitable mounting of the plates, many other applications are possible; such as, creep measurement, determination of flexures or other small displacements. This type of interfermoeter is used for measuring the motion of the pendulum case in the gravity apparatus as used by the U. S. Coast and Geodetic Survey. To obtain sharp fringes, the light beam must consist of parallel rays and the fringes must be viewed along the axis of these rays. The interferometer illuminating and viewing apparatus is designed to fulfill these conditions. It also incorporates additional features; such as, a convenient arrangement of illumination for the plates, a device for easy counting of fringes, and a rotational adjustment to permit viewing a number of interferometers. This viewing apparatus with a low pressure mercury arc and filter permits obtaining fringes with separations of the interferometer plate surfaces up to 1 cm. (path difference of 2 cm.). The Gaertner Scientific Corporation, who manufactures these instruments, has made many improvements in new models. The viewing apparatus is mounted on a cast iron base which holds, in addition, a small table for adjustment of the interferometer and a mercury arc lamp with filters. The light is reflected by a stationary prism along the vertical axis of the viewing apparatus which may thus be rotated between different furnaces and the test table without discontinuity in the illumination and without the necessity for moving the lamp with the apparatus as formerly. The viewing apparatus also has new counting aids for the fringes and a device for checking quickly the leveling parallelism of the plates.

R. H. O.

THE FRANKLIN INSTITUTE.

ANNUAL MEETING, JANUARY 18, 1939.

The annual meeting of The Franklin Institute was held on the evening of Wednesday, January 18, 1939, at 8:15 o'clock with Mr. W. Chattin Wetherill, Vice-President, in the chair.

The Chairman called upon the Secretary who read the report of the tellers of the annual election, which indicated that the following gentlemen were duly elected:

President (To serve 1 year)	Philip C. Staples
Vice-Presidents (To serve 1 year)	Walton Forstall
	W. Chattin Wetherill
	S. S. Fels
Treasurer (To serve 1 year)	Benjamin Franklin
Managers (To serve 3 years)	Edward G. Budd
	Clarence A. Hall
	A. Atwater Kent
	William Fulton Kurtz
	Richard W. Lloyd
	O. J. Matthews
	George W. Pepper
	James S. Rogers

The report was adopted and the Chairman declared the gentlemen named elected to the several offices.

The additions to membership since the last report were as follows:

Active	17
Associate	13
Student	81
Total	111

Announcement was also made of the special meeting scheduled for the afternoon and evening of Tuesday, February 7th. This will be a Transportation Symposium and addresses will be made by engineers, railroad executives, and others.

On Thursday, February 16th, a joint Memorial Meeting will be held with the American Philosophical Society for Dr. Elihu Thomson. The afternoon meeting is scheduled to be held in the Hall of the American Philosophical Society and the evening meeting will be held in the Hall of The Franklin Institute. Prominent scientists will be present on both occasions.

The Chairman then introduced Dr. Frederick A. Saunders, Professor of Physics at Harvard University, who addressed the meeting on "A Scientific Search for the Secret of Stradivarius." The speaker pointed out that the secrets of the best old violins are being sought by exact measurements of their behavior,

in the hope of improving modern instruments. The tests deal with loudness, quickness and ease of response, and the quality, or *timbre* of the tones produced. Modern measurements, impossible before the last decade, have made it necessary to rely on the less accurate estimates by ear. The present stage of these experiments and the rather unexpected conclusions to which they appear to lead were discussed. A test was made to ascertain how many in the audience could distinguish a Stradivarius violin from two others, one a modern German instrument and the other an American instrument made in Philadelphia. These instruments were all played behind a screen in order that the instruments and performer could not been seen by the audience. The audience was then asked to indicate on a card which of the three violins was a Stradivarius. 170 cards were returned and the result indicated that 58 selected the Stradivarius correctly. The subject was also illustrated by lantern slides.

After a brief discussion the Chairman conveyed the thanks of the meeting to the speaker.

Adjourned,

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, January 11, 1939.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 11, 1939.

MR. EDWARD L. FORSTALL *in the Chair.*

The following report was presented for final action:

No. 3059: Recording Spectrophotometer.

This report recommended the award of an Edward Longstreth Medal to Arthur C. Hardy, of Cambridge, Massachusetts, "In consideration of the development of an accurate and reliable instrument which has greatly expedited research in the field of color, both in theory and in its commercial applications."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 822 readers made use of the facilities during the twenty-six days of December.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

WILSON CLOUD MACHINES FOR PORTABLE USE.*

BY

GORDON L. LOCHER.

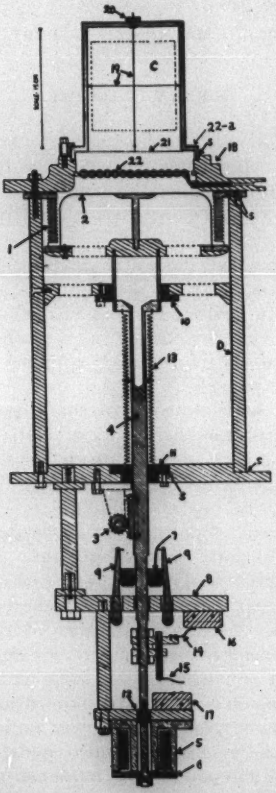
The two Wilson cloud apparatus described were developed for stratosphere balloon flights, and are suitable for general portable use. Built mainly of dowmetal *F*, the machines are of light and rugged construction, and may be operated from small batteries. Both are arranged for automatic expansion by Geiger-Müller counter discharges, since they are designed for photography of cosmic-ray bursts. Both apparatus use the plan, devised by C. T. R. Wilson, of removing expansion turbulence by baffles and gauzes in the cloud chamber, between the region photographed and the region agitated by the expansion.

Figure 1 is a scale drawing of the cross section of this apparatus, in the compressed position. Driving force is provided by the difference of pressure between two pneumatic chambers, of which one is the cloud chamber (*C*) and the other is a sealed cylindrical metal drum (*D*) at a lower pressure. These chambers are separated by a large metal bellows (Sylphon) (1) and a dome of spun brass (2). The gas mixture in the cloud chamber is manually compressed by means of a rack and pinion gear (3), operating on the central drive-rod (4). The pinion is subsequently disengaged by a spring. The apparatus is held compressed by a circular electromagnet and armature (5) and (6), whose force acts centrally along the drive-rod. Expansion is effected by momentarily interrupting the current in the magnet. The lower limit of the stroke, hence the value of the expansion ratio, is determined by the position of a large circular nut of hardened steel (7), whose lower surface bears an annular washer of thick leather. At the end of the stroke, this washer strikes a circular plate (8),

* Reprinted, in part, from a paper which was published in full in the *Review of Scientific Instruments*, 7, 241 (1936).

which is attached to (*D*) by three rods. Two hard steel catches (9), hinged in rigid supports fastened to the plate (8),

FIG. 1.



engage the nut (7) at the end of the expansion stroke. The drive-rod is guided by three bearings (10), (11), and (12). The bearing (11) through which the rod emerges from the

vacuum chamber is pneumatically sealed by a long metal bellows of small diameter (13).

Adjustable arms, carrying phosphor-bronze springs (14) and (15), control the electrical operations attendant on the expansion cycle, through "micro-switches" (16) and (17). Switch (16) (S. P. D. T.) controls the potential of the sweeping electrode of the chamber: a constant potential is applied to it until the instant of expansion; at that time the electrode is grounded, to prevent electric distortion of the tracks. The switch (17) operates the flash of illumination of the cloud chamber, through an adjustable vacuum-tube delay circuit; two other switches, arranged like (17), are provided for other electrically-controlled operations that follow expansion.

The cloud chamber (*C*) consists of a rectangular brass box, with two sides of plate glass (parallel to the plane of the drawing). The brass is 5 mm. thick, and the chamber has internal dimensions: 15.5 cm. by 12.0 cm. by 5.0 cm. The parallel glass windows are for illumination and photography of the sensitive region, in a manner similar to that used by Wilson and Wilson. Two fine wires (19), stretched through the central portion of the chamber and connected to an insulated terminal (20), constitute the ion-sweeping electrode; their photographic images also serve as reference lines for stereo-reconstruction of the tracks. The internal brass surfaces of the cloud chamber are black-nickel plated and painted with Aquadag (colloidal carbon), whose high photoelectric work function minimizes photo-ionization accompanying the illumination of the chamber with intense light, during photography. This coating also reduces the number of natural α-particles from the metal walls to a very low value. The side of the cloud chamber next to the expansion mechanism is a copper gauze (21). This is one of the two baffles used for removing turbulence; it has six 31-gauge wires per cm. The second baffle (22) is an aluminum disk perforated with 6-mm. holes, in a hexagonal pattern. It is interlaced with wicking; this is an important part of the system used for uniformly distributing the vapor used in the chamber.

When a restricted quantity of liquid is used in the cloud chamber, it is found advisable to leave the apparatus expanded for at least 30 seconds after each expansion, to allow re-

evaporation of liquid that is condensed by expansion. A similar period of compression is desirable, before expansion, for the establishment of thermal equilibrium. If the expansions are not too frequent, intermediate partial expansions have not been found necessary. The stability of this machine is shown by the fact that it has been used for more than a year, without alteration of the cloud atmosphere, or any adjustment whatsoever.

This machine has not been used at pressures above one atmosphere. However, the construction should permit the use of higher pressures, up to the limit of the mechanical strength of the cloud chamber and the vacuum drum, provided the two chambers are pumped up simultaneously.

OPTICAL ARRANGEMENT.

The transmission of light through the chamber greatly enhances the luminosity of the drops, because light is scattered from them at angles approaching 180°. This arrangement solves the troublesome problem of getting a source of sufficient intensity and convenient form, especially for cloud machines to be used in the absence of a laboratory power supply. In the present arrangement, light from a restricted area is made nearly parallel with a condensing lens of approximately the same diameter as the windows of the cloud chamber, and passes through the chamber in such a manner that it does not strike the camera lenses. Leica cameras, in rigid and accurate mountings, are used with their optic axes intersecting in the center of the chamber at an angle of 30°. (The lenses have been moved out by shims 1.00 cm. thick; the magnifications are carefully equalized, to prevent distortion of the stereoscopic photographs.) Stereophotographs taken at an angle of 30° can be viewed with a suitable stereoscope, without undue strain on the eyesight. A light-tight box encloses the entire optical system; the camera shutters are left open, so the instant of photography is determined by the timing of the light flash.

Apertures of $f:8$ to $f:9$ are ample for obtaining good photographs of electron tracks on Eastman sound-recording positive film, when the light source is a No. 10 Photoflash lamp (smallest commercial size). The depth of focus resulting from this low aperture is sufficient to give sharp track images throughout the chamber.

Flash bulbs are very convenient for cloud photography, but they are too costly for extensive work of this kind. A simple spark illuminator, using only 10 watts of power, has accordingly been made to replace them. This consists of an 8-mf condenser, charged to 3000 volts by a small kenotron and neon sign transformer, and connected to a 3.5-mm. calcium-to-magnesium gap, in air. Since 3000 volts is insufficient to start the discharge, an auxiliary gap, excited by a small high tension transformer that operates from the light delay circuit, is used to initiate the discharge at the desired moment. One of the electrodes of the auxiliary gap is the magnesium electrode of the illumination gap; the other auxiliary gap electrode is coaxially mounted in a hole drilled through the first, in such a manner that the abundant ions from the auxiliary discharge initiate the discharge in the main gap. The light from the spark is rich in blue and violet, so ordinary blue-sensitive film seems to be about as sensitive as any other, for this kind of photography.

The cloud machine described above was designed for the stratosphere flight of Dr. and Mrs. Jean Piccard (1934). Its weight, exclusive of accessories, is 34 kg.; the power consumption, including that of the spark illuminator, is about 25 watts.

COSMIC-RAY OBSERVATIONS IN THE STRATOSPHERE.*

BY

W. F. G. SWANN, G. L. LOCHER, W. E. DANFORTH, C. G. MONTGOMERY and D. D. MONTGOMERY.

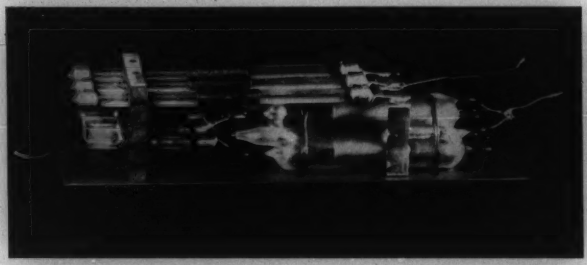
The problems investigated were the variation of intensity of cosmic radiation with altitude and zenith angle.

The apparatus is an improved design based upon the apparatus which we installed in the first National Geographic Society–U. S. Army Air Corps stratosphere flight and the Piccard flight. It comprised 210 Geiger-Müller counters arranged in the form of ten independent telescope systems, each of which itself comprised two individual telescope systems in parallel.

* Condensed from three papers published in full in the *National Geographic Society Contributed Technical Papers*, Stratosphere Series No. 2, pp. 13–31 (1936).

Each individual telescope system comprised three units in line, and one of these units is represented in Fig. 1, which is explained by its caption.

FIG. 1.



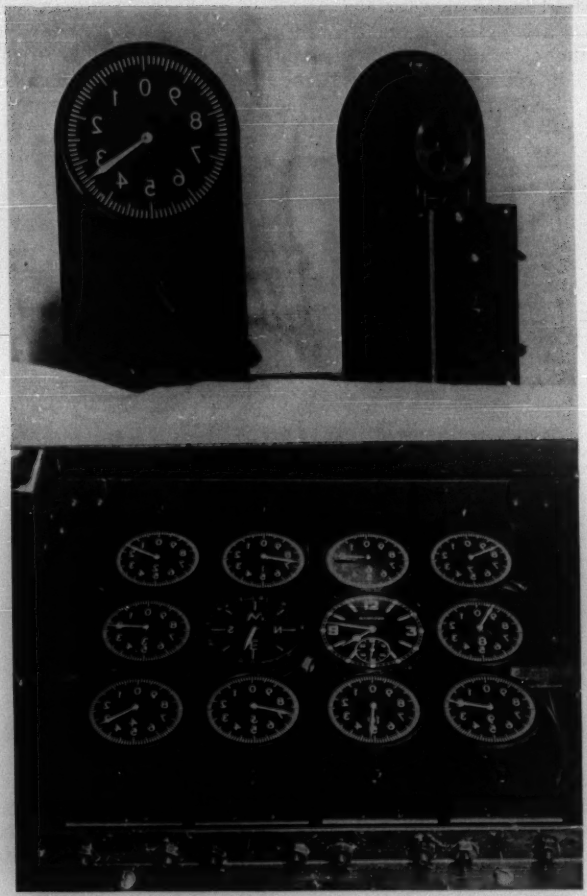
The three larger tubes to the right, two of which are visible, represent one counter group. Three such groups represent a single counter telescope. Two such telescopes were contained in each of the boxes *A*, shown in Fig. 9. The long tubes at the top are the high resistances, and below them to the left are the electrical condensers which form part of the regular equipment of a Geiger-Müller counter unit.

Two methods of recording cosmic-ray impulses were adopted. In the first there was a system of ten dials separated by ten solenoids, which were energized through an amplifier by the cosmic-ray impulses. With these ten dials were associated an ordinary watch and a compass, the details of these pieces of apparatus being shown in Figs. 2 and 3. The second method of recording involved opening an optical shutter by each cosmic-ray impulse, the corresponding flash of light being photographed upon moving photographic paper. The details are represented in Fig. 4, and the two types of record are indicated in Figs. 5 and 6.

The results of these experiments are best represented by the curves in Fig. 7. Further details will be found in the complete publication (*National Geographic Society Contributed Technical Papers*, Stratosphere Series, No. 2).

The apparatus for observing large atomic bursts comprised a dowmetal sphere filled with argon under pressure and provided with a central insulated system connected to two electroscopes which were caused to register upon moving film contained in two cameras. The details of this apparatus are

FIG. 2.

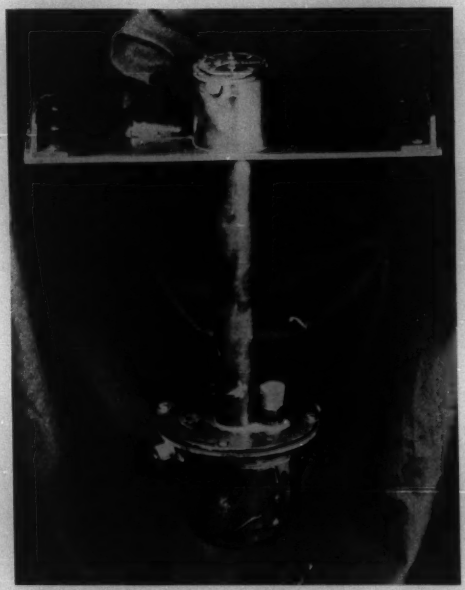


The cut shows the ten bordering dials associated with the ten counter telescopes; a Hamilton Watch; and a compass.

shown in Fig. 8 and the complete assembly of all the apparatus described is shown in Fig. 9.

The details of the experiments on bursts are contained in the reference already cited, and it will be sufficient to state the main conclusion, which is to the effect that the rate of increase

FIG. 3.



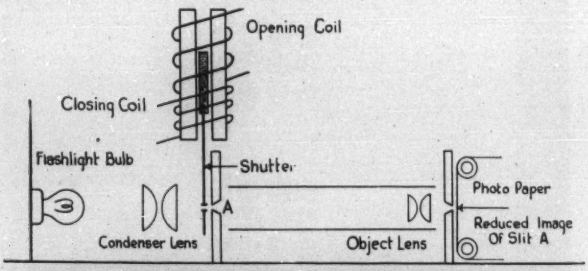
The magnetic compass before mounting. The dial of this instrument is shown in Fig. 2.

of the numbers of the larger bursts with altitude does not continue to show itself for high altitudes in the same degree as would be suggested by the rate of increase of bursts of slightly smaller size from sea-level to Pike's Peak.

Fig. 10 shows a special form of counter-controlled Wilson cloud chamber apparatus devised by Dr. G. L. Locher for use

in the stratosphere measurements. While it had to be discarded on account of the necessity of conservation of space in the gondola and of the energy of the observers, its details are of interest.

FIG. 4.

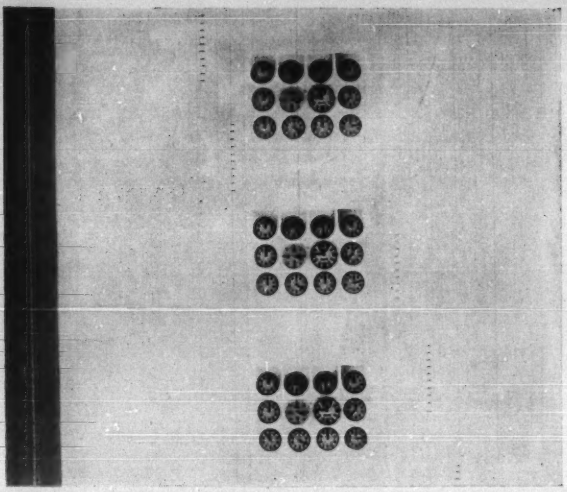


The upper portion of the cut is a diagram of one of the optical recording units. A group of units is shown below. Normally, the slit at *A* in the diagram was closed by the shutter behind it. The pulse operated the upper part of the solenoid, pulling up the plunger and letting light through.

The cloud chamber (left) was connected to the expansion mechanism (right) by four stiff rubber tubes, *T*, so that the assembly could be fitted to the contour of the gondola. The hood, cameras, and light source, which were attached to the cloud chamber, are not shown in the photograph.

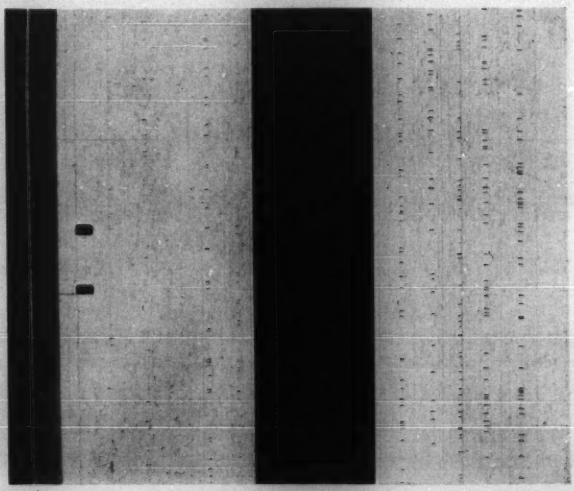
The cloud chamber, *C*, is a glass cylinder 15 centimeters in diameter and 5.6 centimeters high, bolted to a dowmetal

FIG. 5.



The short horizontal lines in vertical columns are records of pulses from the counter circuits. The white line on the extreme left represents the record of the level indicator.

FIG. 6.



The cut shows a piece of the optical record obtained in the stratosphere. The dark bar in the center was caused by the sticking of a clock mechanism. Numerous records of cosmic-ray impulses are seen on each side. The two black dots to the left are time signals.

FIG. 7.

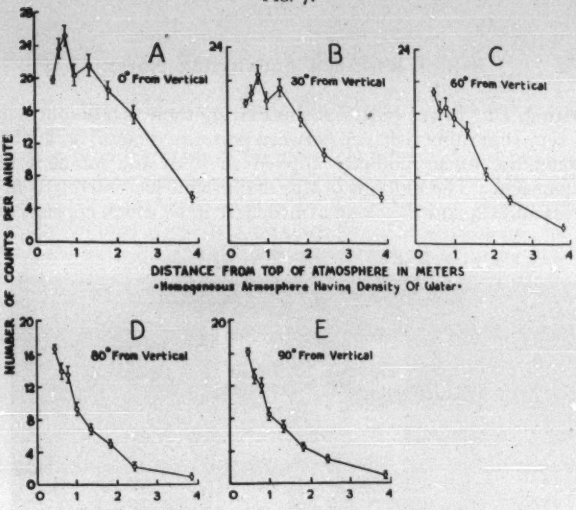
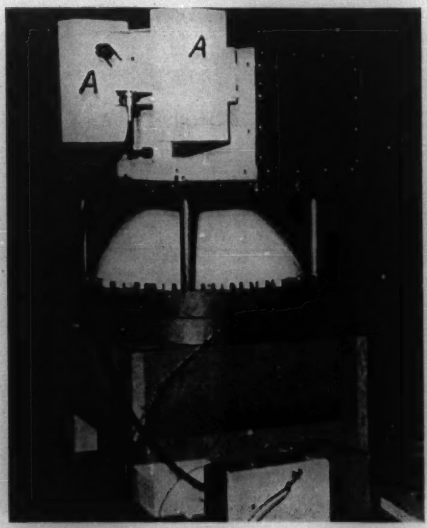


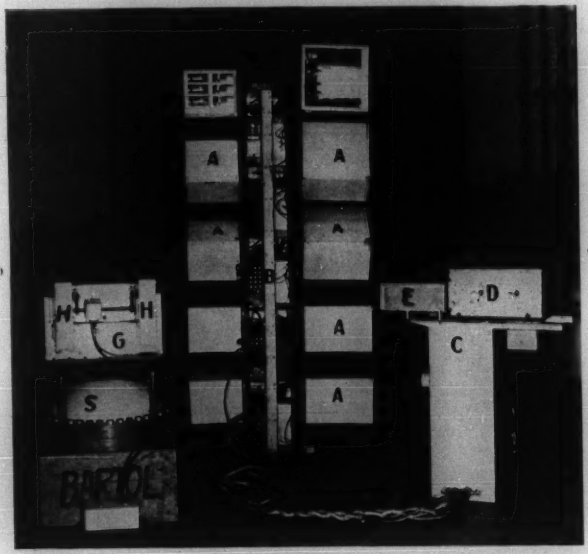
FIG. 8.



The dowmetal sphere is shown at the center. Above is a box containing two electroscopes, the electrical system, and an optical system which focuses the electroscope fibers on the films in the cameras *A*. Between the cameras is the motor which drives the films.

casting, *D*. In the center of this casting there is a diaphragm of very thin rubber, driven between perforated metal baffles by pneumatic force suddenly applied to it at the moment of expansion. The motions of this diaphragm successively compress and expand the cloud atmosphere in *C*, which consists of

FIG. 9.



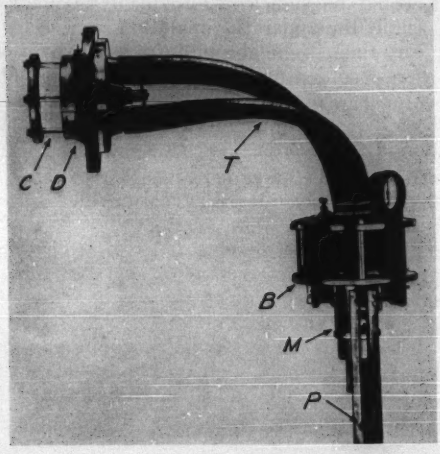
The ten boxes marked *A* (top two open) contained cosmic-ray telescopes. The passage of cosmic rays was recorded photographically in camera *D*. The impulses initiated by the rays also registered on the ten counter dials in box *C*. Camera *D* photographed these dials. The sphere *S* (the atomic burst chamber) contained compressed nitrogen. Above it was a slab of lead. A sudden increase in the ionization of the gas was recorded through the electrical apparatus *G* and the cameras *H*.

argon gas saturated with *n*-propyl alcohol. The force for driving the diaphragm is supplied by a closed single-stroke sylphon bellows pump, *B*, which is compressed by a pedal, *P*. The pump (hence the cloud atmosphere) is held compressed by an electromagnet, *M*, that can be released very quickly, either by opening a switch or by the coincident discharge of a

set of Geiger-Müller counters placed above and below the cloud chamber.

Stereo-photographs of the cloud chamber were taken on 35 millimeter Eastman Super-X Panchromatic film used in a pair of special Factograph cameras, built and lent for the purpose by the Folmer Graflex Corporation. These cameras were mounted with their optic axes intersecting at an angle of 25° in the cloud chamber; they were operated without shutters at

FIG. 10.



an aperture of f : 3.8. The films were automatically advanced after each exposure by the recompression of the bellows pump. Illumination was furnished by small photoflash bulbs, of which 100 were prepared for the flight.

The cloud chamber was provided with three sets of Geiger-Müller counters whose coincident discharge initiated the expansion; one counter group was above the chamber and two were side by side below it, so that the simultaneous passage of two or more ionizing rays through the chamber started the expansion. A block of paraffin, approximately 12 centimeters

thick and 500 cubic centimeters in volume, was placed above the upper counter as a burst-generating material. In addition to the paraffin, a sphere containing 500 pounds of lead shot (part of the apparatus of the California Institute of Technology) was nearly above the cloud chamber; it was expected that bursts in the lead would contribute some secondary cosmic-ray tracks whose origin could be established from the stereo-reconstruction of the photographs.

Since it was impossible to tell, before the flight, whether or not the production of cosmic-ray bursts in the overlying materials would be sufficiently frequent to make counter control feasible, the apparatus was also arranged for manual release at any time. The absolute times of expansion of the machine were recorded on a continuously-moving film (part of the counter-telescope recorder), in order that the elevation at which each picture was taken could be established by coördination of the records.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Reactions of Dyes with Cell Substances. IV. Quantitative Comparison of Tissue Nuclei and Extracted Nucleoproteins.—EDWARD G. KELLEY. (*Journal of Biological Chemistry*, **127**: 55, Jan. 1939.) Two fundamental questions concerning the chemistry of the cell nucleus have been investigated. Nucleoproteins obtained from various tissues have been studied with the aim of answering these two questions: What relation does the extracted substance bear to the cell nucleus from which it was obtained in its nucleic acid to protein ratio; and what is the relation of the isoelectric point of the extracted substance as found by cataphoretic measurement to the so-called isoelectric point of the nucleus as determined by combination with acid and basic dyes? Four preparations of nucleoproteins were made from each of the following: Walker No. 256 tumor tissue, Philadelphia No. 1 tumor tissue and Rat thymus tissue. These preparations showed that it was possible to obtain nucleoproteins having constant nucleic acid to protein ratios and constant isoelectric points from a number of batches of the same tissue. Of the three tissues studied, rat sarcoma (Philadelphia No. 1 tumor) contained a nucleoprotein having a nucleic acid to protein ratio (or P/N ratio) of 1 : 15.3. Rat carcinoma (Walker No. 256 tumor) contained more nucleic acid in relation to protein and had, therefore, a lower nucleic acid to protein ratio at a value of 1 : 9.85. Rat thymus had the lowest nucleic acid to protein ratio at a value of 1 : 5.9.

A standing technique was worked out which enabled a comparison to be made between the so-called isoelectric point of the cell nucleus and the cataphoretic isoelectric point of the extracted nucleoprotein. A dye extraction technique using thorium nitrate solution to remove the dye from either dyed cell nucleus or extracted nucleoprotein was also developed. Colorimetric comparison of the extracted dye solutions enabled an accurate determination of the relative

amount of basic dye bound by different types of nuclei and of nucleoproteins.

These two investigations showed that the dye binding of a nucleoprotein or tissue nucleus was independent of the electrostatic charge which determined the cataphoretic isoelectric point of the substance, but was dependent upon the charge on the nucleic acid portion of the nucleoprotein both in the extracted form and in the cell nucleus. The amount of dye bound by a particular nucleoprotein or tissue nucleus was directly proportional to the amount of nucleic acid in the extracted substance or nucleus.

The action of fixatives such as mercuric chloride and formaldehyde on the quantitative dye binding of the nucleoproteins was investigated and its significance has been discussed in detail.

Reactions of Dyes with Cell Substances. V. Differential Basic Dye Combination of Tissue Nuclei with Special Reference to Resting and Mitotic Cells of Tumor Tissue.—EDWARD G. KELLEY. (*Journal of Biological Chemistry*, **127**: 73, Jan. 1929.) Correlation of the nucleic acid content and the dye binding of extracted nucleoproteins with the dye binding of tissue nuclei has led to the interesting conclusion that the binding of basic dye by a cell nucleus is strictly proportional to the nucleic acid content of the nucleoprotein of this nucleus. This work was described in Part IV. Based on this finding, a differential pH stain technique, which allows the detection of very fine differences in the visible amount of dye bound by various types of nuclei, has been developed. This technique and its use in showing the relative nucleic acid content of the nuclei of various rat tissues is described in detail.

The most interesting finding as shown by the above methods was that the mitotic cell nucleus of tumor tissue contains a nucleoprotein of higher nucleic acid content than the resting cell nucleus. During cell division either more nucleic acid goes into the chromatin material or protein is split off from it leaving a nucleoprotein of greater nucleic acid content.

Of the tissues studied, lymphocytes were found to contain

the most acid nucleoprotein, with other nuclei containing less acid nucleoproteins in the following order: thymocytes, mitotic tumor nuclei, reticular cell nuclei of spleen, resting cell nuclei of Walker No. 256 tumor, liver nuclei, and resting cell nuclei of Philadelphia No. 1 tumor. The action of fixatives on nuclear staining by the above method has also been discussed, with special reference to the differential effect of mercuric chloride on the mitoric and resting nuclei of tumor tissues.

The part of the work devoted to the investigation of the dyeing of kidney tissue led to some interesting findings which may have some future bearing on the study of kidney metabolism. Kidney tissue fixed in alcohol showed greatly inhibited nuclear staining in the proximal and distal convoluted tubules. At points on the pH scale of the differential pH stain series at which the nuclei of the glomeruli and of the medullary zone tubules were strongly dyed with toluidine blue there was no dyeing of the nuclei of the proximal and distal tubules. Nearly full intensity of staining could be reached at a higher pH value in the stain series. In mercuric chloride fixed tissue strong nuclear staining occurred in all of the tubules at nearly the same pH values. Whatever caused the inhibition of staining in alcohol fixed tissue was not present in the mercuric chloride fixed tissue. It was suggested that water soluble basic salts in the proximal and distal tubules, which would inhibit basic dye combination with the nucleoproteins, would be washed out during the process of mercuric chloride fixation but would not be removed in alcohol fixation because of the absence of water rinses after the completion of the fixation.

BOOK REVIEWS.

THE PROPERTIES OF GLASS, by George W. Morey. 561 pages, illustrations, tables, 16 × 23 cms. New York, Reinhold Publishing Corporation, 1938. Price $12.50.

The fact that this book is one of the American Chemical Society Monograph Series is sufficient to indicate its good quality. It is safe to say that each book in this series is an outstanding work reflecting adequately and thoroughly the state of the topic covered. This book on the properties of glass rightly belongs in this class.

Only a comparatively short time ago there was little known regarding the properties of glass, and what there was, was due to the work of a small group of men. The author states this condition existed in 1924 when work on this monograph was begun. Because of certain researches which were then carried on, it being desirable to include the results from them, the publication was delayed and consequently the work now here, is broader in scope. As an illustration of the conditions during this time the author points to the 781 literature references made in the book, of which 478 refer to work published since 1920, and 399 to work published since 1924. The reason given for this rise in interest is the realization by the glass industry that the soundest foundation for a strong industry is the understanding of its fundamental scientific principles.

The chemical relationships between composition and properties of glasses form the subject matter of this book. After presenting a brief history of the glass industry and giving a definition of glass, the subject matter is divided conveniently according to pertinent sub-headings such as chemical durability, viscosity, annealing, surface tension, heat capacity and conductivity, density, coefficient of expansion, elastic properties, strength, thermal endurance, hardness, optical properties, and electric and magnetic properties of glass. In each of these divisions or chapters the information in the literature is summarized, and to some extent discussed critically. Measurements on glasses of known composition are quoted whenever possible. Much of this information deals with simple glasses, prepared to ascertain the effect of change in composition on properties. Measurements on multi-component commercial glasses also have been included, especially when the composition is known.

The literature on glass is spread over a considerable area and that on the properties of glass is of widely differing accuracy and reliability. The work presented in this book is the result of a careful and exhaustive search. A special feature is the up-to-dateness of the summarization and the definite indications of the directions of future research for the determination of the unknown with respect to glass. The manner of exposition is such that any part of the mass of information and data can be quickly referred to.

R. H. OPPERMANN.

THE BOOK OF TIME, by Gerald Lynton Kaufman. 287 pages, plates, 15 × 22 cms. New York, Julian Messner, Inc., 1938. Price $3.00.

"It is always difficult to define the abstract. Yet it is essential to establish the meaning of a concept before taking up its study. In the case of Time, however, we find ourselves confronted with the most abstract of deductions. We are dealing with a combination of concept and percept; with an abstract which constantly merges into something concrete, while manifesting itself simultaneously in our consciences, in our physical bodies, and in the world of Things-in-themselves. Hence, the more we search through dictionaries and encyclopedias for a definition of Time, the more disappointed we must become, for every definition of Time is in terms of Time itself." Thus is the opening paragraph of this book, which is an attempt to make popular a subject that is so near to each of us that we have utterly failed to notice it. The importance of time cannot be exaggerated, whether it be its nature or its quantity. This book reveals that there is a surprising amount of information on the subject, yet it remains an elusive property of the scientists, philosophers and savants.

The book is divided into seven parts, arranged and written so as to present an informative story, readable and digestible to the intellectually curious. A basis is used of an alphabetical list of some varieties of time encountered in science, philosophy, and everyday life, as a preparation for elaboration later in the book. A part on time measurement discusses natural time, earth time and clock time, the calendar of today and the future, and standard time. The various phases of time are so interlocked and interwoven that in the remainder of the divisions of the book, free use is made of whatever phase fits in with the particular discussion at hand. Hence there is to be found in several instances the Theory of Time Dimensions as originally advanced by P. D. Ouspensky, the research of Eddington, Jeans and Einstein, and the Michelson-Morely experiment. The method of these injections is clever, being submerged in division titles of adventures in time science and time dimensions, time and again, from time to time, and time without end. The material used, taken in its entirety comprises a collection of facts arguments, theories and fancies well pieced together and bearing on the nature of time rather than on quantity.

The reader of this book will certainly receive a stimulus to his imagination. It raises innumerable questions; it certainly makes clear the disorganization that exists in knowledge of the subject; and it reveals the vastness of the subject to be beyond present comprehension. A feeling is developed akin to that experienced when peering through a telescope into limitless space.

R. H. OPPERMANN.

KURZES LEHRBUCH DER PHYSIKALISCHEN CHEMIE, von Dr. Karl Jellinek. Heft 1, 314 pages, illustrations, tables, 16 × 25 cms. Deventer, Æ. E. Kluwer Ltd., 1938. Price 8.50 R.M.

Physical chemistry is a subject which is becoming important in many fields of scientific pursuit. It is a factor to be contended with in physics, mineralogy, medicine and others. In fact, progress in the state of knowledge in this line in general, together with its special branches, places it as a separate and distinct study and a recognition of this by workers in fields more or less dependent is at hand. There is need for a short but comprehensive and thorough text for these workers,

who while not wishing to specialize, need a good background of knowledge of the subject.

The author has had many years experience with this subject in theoretical, experimental, and practical application and the book at hand is the first of a series of short texts intended to satisfy such need. It consists of five chapters dealing with a division of the elements of the subject suited to those who have a groundwork in physics and chemistry. As an introduction, the fundamental principles of physical chemistry are laid down in a careful manner with special reference to the elements of thermodynamics. This is followed by treatments on the kinetic gas theory, the laws and theory with respect to pure substances, dilute gas mixtures and dilute liquid solutions of non-electrolytes, concluding with mixtures of any concentration and physical condition.

The treatment of this subject necessarily requires a considerable use of mathematics. The book here is no exception, but as a prerequisite it is assumed the elements of differential and integral calculus have been mastered. There are some places where it would be well to have a little advanced knowledge to save time only, although it is perhaps best to follow through slowly. There are numerous computations and derivations carried through from beginning to end which are essential to follow to give complete familiarity.

The book contains a clear but vigorous treatment of the subject within the limitations of the title. Other than a somewhat detailed table of contents there is no subject index. The use of the book is restricted to those having a fair knowledge of the German language.

R. H. OPPERMANN.

CHEMISTRY OF THE PROTEINS, by Dorothy Jordan Lloyd and Agnes Shore. Second Edition, 532 pages, illustrations, 13 × 20 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1938. Price $5.50.

Proteins form the substance of the living body of all plants and animals and exist in every cell. The importance of this subject places it in the class which is among the foremost in modern development. It has direct bearing in a number of scientific fields including biochemistry, physiology, and pathology, and because of this, knowledge has advanced not only within the limits of the subject itself but in each of these activities which in turn may or may not have applicability in other diverse fields. With this in mind, a central point from which all may obtain a timely review of the state of knowledge is certainly an efficient tool of utility which will aid in application and further progress.

"Chemistry of the Proteins" contains the results of a search through many branches of literature. The findings are presented in the nature of a summarization and the coverage is from all parts of the world. The subject is handled under two headings, the constitutional chemistry of the proteins and the physical chemistry. Under the former is discussed the nature, occurrence, composition, properties and reactions of the proteins; different classes of proteins such as the simple proteins, the protamines, the histones etc., the conjugated proteins, and the derived proteins; the methods of protein analysis; the individuality of the proteins and their identification by various methods; the biochemistry of proteins and amino acids; the proteolytic enzymes; and the linkages in the protein molecule.

Under the second heading there is treated the architecture of the protein molecule—the potentialities of the polypeptide chain, X-ray investigations, the evidence of the ultracentrifuge, the transformation of the protein molecule; the combination of proteins with acids and alkalies; the properties of protein solutions and their theory; the absorption and loss of water by gels and tissues; the specific effects of salts; denaturation and coagulation.

This separation of headings is in a formal sense only. The bearing of one upon the other is kept clearly before the reader, exhibiting an unusual combination of mastery of the subject with the art of presentation. At the end of each chapter there is a bibliography and at the end of the book there is a name and subject index. The applications of protein chemistry to technology and industry, a field which has experienced tremendous development, has not been included.

R. H. OPPERMANN.

A MANUAL OF EXPERIMENTS, TO ACCOMPANY A FIRST COURSE IN PHYSICS FOR COLLEGES, by Robert Andrews Millikan, Henry Gordon Gale and Charles William Edwards. Revised Edition, 221 pages, illustrations, tables, 20 × 26 cms. Boston, Ginn and Company, 1938. Price $1.10.

The study of any scientific subject requires a well ordered mind. As a student progresses from the elementary to the more advanced studies this is impressed gradually in direct and indirect ways. When college grade work begins there certainly can be no question as to its necessity.

The book, at hand, devoted to the subject of physics, can rightly be classed as more than a mere description of how to perform experiments and evaluate their results. It provides the basis for the habit of orderliness, and the teaching to collect and organize related data in such a way as to draw valid conclusions. From these the spirit of investigation is a quality which can be fostered, as well as the high order of creative thinking. As the title implies, the coverage is elementary. There are some two hundred and eleven experiments which may be performed with laboratory apparatus of small cost. The subjects generally deal with mechanics, heat, magnetism, electricity light, and sound. There is an introduction given to every experiment to give aid in correlating the exercises with previous experiments, with the text, and with every day life. General directions at the beginning explain the principles of errors of measurement and comparisons of precision, curve plotting, the use of calipers and procedure in the laboratory, such as the recording of observations and the writing of reports.

The book can well be considered as a laboratory supplement to a modern physics text.

R. H. OPPERMANN.

SOME NOTES ON LEAST SQUARES, by W. Edwards Deming. 181 pages, illustrations, 20 × 26 cms. Washington, The Department of Agriculture, 1938. Price $1.50.

The title of "Some Notes on Least Squares" is indicative that the treatment here is primarily of a reference nature and secondly a text. This being the case, it is necessary that the user of the book first of all become oriented by reading the preface. Here it is explained that the contents of this book are lecture notes for the last six weeks of a course in statistics given at the U. S. Department of Agri-

culture Graduate School. The material presented here may therefore be regarded purely as an exposition on the principle and method.

At the very beginning the author calls attention to the importance of the historical aspects of the subject. It is his belief, and he makes references which give weight to his belief, that Karl Friedrich Gauss accomplished most of what we think we know now about least squares. The lack of familiarity with this fact has caused no little confusion. More than once a profound "discovery" in modern statistics has turned out to be something already known under other forms to those with classical training. Also, a similar difficulty may be experienced by disregarding more modern developments. The notes here recorded may be used as a step toward unifying some closely related topics in least squares and statistics.

The book is divided into three parts proceeding from some simple to the more complicated problems in curve fitting and lastly, application to curve fitting. It is essentially for the consideration of teachers. A considerable number of references are given for supplementary reading, a perusal of which will furnish valuable assistance.

This is a book which covers in a novel manner that part of the subject from which a broader conception may be obtained.

R. H. OPPERMANN.

PROCEDURES IN EXPERIMENTAL PHYSICS, by John Strong and others. 642 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1938. Price $5.00.

The modern laboratory worker, in addition to being an expert technician, must be an ingenious mechanic in the construction and use of laboratory devices to gain desired ends. He must know materials and their properties, and be able to choose and fashion them, also he must keep well informed as to new developments and new methods of use. Take the material, glass, for instance. The fundamental operations in glass blowing for laboratory use are cutting, rotating, bending, blowing, and welding. By various combinations of these operations, apparatus is constructed from glass tubing and glass cane.

The present book is devoted to such procedures, explaining how these operations are executed. It opens with a chapter on glass concerning the above mentioned operations with especial reference to hard glass like Pyrex which is a newer material and more difficult to handle. Optical work often confronts the research worker when it is necessary to prepare optical surfaces required for mirrors, prisms, interferometers, lenses, etc. The book has a chapter on this technique. It also discusses the technique of high vacuum which is preceded by a basic discussion on some of the equations from the kinetic theory.

Other topics similarly covered are the coating of surfaces, the use of fused silica, electrometers and electroscopes, Geiger counters, vacuum thermopiles and the measurement of radiant energy, optics, photoelectric cells, photography in the laboratory, materials of research, and notes on the construction and design of instruments and apparatus such as the use of the lathe, soft and hard soldering, spot welding, and molding and casting.

It is essentially a book on practical application and many of the procedures appear here in print for the first time. Fundamental theoretical information is freely given wherever necessary to assist the practice described. Of course the

ideal way to learn the practices covered is by actually performing them, but rather than endeavoring to perform them by the tedious manner of hit or miss, the assistance of the instructions as given will save valuable time and produce a better job. The illustrations in the book go far toward bridging the gap between laboratory demonstrations and experience on the one hand, and the exposition on the other. The method of presentation of the material in the book makes for ready understanding.

A comprehensive subject and name index in the back enhances the value of the book for quick reference. Because of this and because it is just cramed full of up-to-date usable material, it should be within easy reach of every laboratory worker.

R. H. OPPERMANN.

STELLAR DYNAMICS, by W. M. Smart. 434 pages, illustrations, tables, 18 × 26 cms. Cambridge, The University Press, 1938. Price $8.50.

The popular conception of fixed stars is one which satisfies present popular interest in-so-far as differentiating between heavenly bodies which have regular motion and those which do not. Persons whose business it is to observe and survey the heavens have long ago noticed certain differences in these bodies which led to considerable investigation. In 1718 it was noticed by Halley that the positions of three bright stars—Sirus, Arcturus and Aldebaran—were appreciably different from the positions as recorded in the catalogue of Hipparchus, compiled more than eighteen centuries before. Since Halley's time precise observations have shown that every star examined is in motion and the conception of a fixed stellar background in theory is cast aside. In practice, the idea of a fixed stellar background can be retained as concerns stars of the twentieth magnitude which are, in the main, so distant that linear cross-velocities of the ordinary stellar size would be insufficient to change the directions of the stars by an observable amount even after the lapse of a century.

Stellar dynamics is a comparatively new subject which has grown within the space of a third of a century to such dimensions as to constitute one of the most important departments of theoretical and observational astronomy. The book at hand is an attempt to present the subject in its full mathematical and observational development. The introduction gives a general description of the galactic system and the correction of observational statistics. After this there is given the mathematical theory of a single star drift; a detailed discussion of solar motion in many of its aspects including historical, theoretical and practical; the theory of the two star streams and Schwarzschild's ellipsoidal hypothesis in detail, where special emphasis is laid on the practical applications of the several theoretical methods described; various methods of deriving statistical parallaxes of the stars from a knowledge of their proper motions, with due consideration of their distribution in the sky; the space distribution of the stars where Dyson's formula is made the basis of an investigation dealing with proper motions; general theorems of stellar statistics; star clusters dealing with moving open and globular clusters with sections on the galactic absorbing cloud; the fundamental work of Jeans and Eddington on the dynamics of the stellar systems; the galactic rotation; the dynamics of the galaxy incorporating several recent researches on different aspects of galactic phenomena.

The book is systematic in its accounting of the subject. It should furnish sufficient groundwork for further study.

R. H. OPPERMANN.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. Transactions, Volume 131, Iron and Steel Division, 1938. 448 pages, illustrations, plates, 16 × 24 cms. New York, Institute.

This volume is the eleventh of a series containing papers and discussions presented before the Iron and Steel Division of the A. I. M. & M. E. since its organization in 1928. It covers the meetings at Atlantic City, Oct. 18–21, 1937; New York, Feb. 14–17, 1938; and Buffalo, April 20–22, 1938. There is much of interest to a wide circle. Eight papers on blast furnace problems, two on ingots, a very interesting paper on Professor Read's ancient Chinese castings, and one on the use of statistics in quality control; with nine good papers on general metallurgy and the excellent Howe Memorial Lecture make a well rounded book. A new feature is the inclusion of the index of the current Institute of Metals Division.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 635, Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist, by Henry A. Pearson and Robert T. Jones. 17 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Stability derivatives have been computed for twisted wings of different plan forms that include variations in both the wing taper and the aspect ratio. Taper ratios of 1.0, 0.50, and 0.25 are considered for each of three aspect ratios: 6, 10, and 16. The specific derivatives for which results are given are the rolling-moment and the yawing-moment derivatives with respect to (*a*) rolling velocity, (*b*) yawing velocity, and (*c*) angle of sideslip. These results are given in such form that the effect of any initial symmetrical wing twist (such as may be produced by flaps) on the derivatives may easily be taken into account.

In addition to the stability derivatives, results are included for determining the theoretical rolling moment due to aileron deflection and a series of influence lines is given by which the loading across the span may be determined for any angle-of-attack distribution that may occur on the wing plan forms considered. The report also includes incidental references to the application of the results.

Report No. 641, The Negative Thrust and Torque of Several Full-Scale Propellers and their Application to Various Flight Problems, by Edwin P. Hartman and David Biermann. 18 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Negative thrust and torque data for 2-, 3-, and 4-blade metal propellers having Clark Y and R.A.F. 6 airfoil sections were obtained from tests in the N.A.C.A. 20-foot tunnel. The propellers were mounted in front of a radial engine nacelle and the blade-angle settings covered in the tests ranged from 15° to 90°. One propeller was also tested at blade-angle settings of 0°, 5°, and 10°.

A considerable portion of the report deals with the various applications of the negative thrust and torque to flight problems. A controllable propeller is shown to have a number of interesting, and perhaps valuable, uses within the negative thrust and torque range of operation. A small amount of engine-friction data is included to facilitate the application of the propeller data.

PUBLICATIONS RECEIVED.

Man and His Lifebelts, by E. T. Bell. 340 pages, 15 × 22 cms. Boston, The Williams & Wilkins Company, 1938. Price $3.00.

Precis de Chimie Physique, par A. Berthoud. 498 pages, illustrations, 17 × 25 cms. Paris, Gauthier-Villars, 1939. Price 155 francs.

Research and Statistical Methodology, Books and Reviews of 1933–1939, by Oscar Krisen Buros. 100 pages, 16 × 24 cms. New Brunswick, Rutgers University Press, 1938. Price $1.25.

Elementary Matrices and Some Applications to Dynamics and Differential Equations, by R. A. Frazer, W. J. Duncan and A. R. Collar. 416 pages, illustrations, tables, 16 × 25 cms. Cambridge, The University Press, 1938. Price $8.50.

The Scientist in Action, by William H. George. 354 pages, illustrations, 14 × 23 cms. New York, Emerson Books, Inc. Price $3.00.

Fundamental Principles of Physics, by German G. Heil and Willard H. Bennett. 631 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1938. Price $3.75.

Physics, A Textbook for Colleges, by Oscar M. Stewart. Third Edition, 750 pages, plates, illustrations, 16 × 24 cms. Boston, Ginn and Company, 1939. Price $4.00.

A System of Chemical Analysis for the Common Elements, by Ernest H. Swift. 589 pages, illustrations, tables, 16 × 23 cms. New York, Prentice-Hall, Inc., 1939. Price $4.25.

Grimsehls Lehrbuch Der Physik, von Dr. R. Tomaschek. Erster Band, 681 pages, illustrations, 15 × 23 cms. Leipzig, B. G. Teubner, 1938. Price 19.80 R.M.

The Mobility of Positive Ions in Gases, by A. M. Tyndall. 93 pages, illustrations, tables, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $1.75.

Quelques Questions de Mecanique et de Physique Mathematique, par V. Volterra. 82 pages, illustrations, 17 × 25 cms. Paris, Gauthier-Villars, 1938. Price 40 francs.

A Yearbook of Railroad Information, 1938 edition. 96 pages, 10 × 15 cms. New York, Committee on Public Relations of the Eastern Railroads.

U. S. Department of Commerce, National Bureau of Standards, Research Paper RP1137, A Determination of the Absolute Ohm, Using an Improved Self Inductor, by Harvey L. Curtis, Charles Moon and C. Matilda Sparks. 48 pages, illustrations, 15 × 23 cms. Washington, Superintendent of Documents. Price 15 cents.

National Advisory Committee for Aeronautics, Twenty-fourth Annual Report, 1938. (Administrative Report without Technical Reports.) 47 pages, 23 × 29 cms. Washington, Superintendent of Documents. Price 20 cents. Technical Notes: No. 679, Noise from Propellers with Symmetrical Sections at Zero Blade Angle, II, by A. F. Deming. 19 pages, illustrations. No. 680, The Aerodynamic Drag of Five Models of Side Floats, N.A.C.A. Models 51-E, 51-F, 51-G, 51-H, and 51-J, by R. O. House. 9 pages, illustrations. No. 681, A General Tank Test of a Model of the Hull of the P3M-1 Flying Boat Including a Special Working Chart for the Determination of Hull Performance, by John R. Dawson. 27 pages, illustrations. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1938.

Bell Telephone System, Monographs: B-1093, Currents to Conductors Induced by a Moving Point Charge, by W. Shockley. 4 pages, illustrations. B-1094, The Time Lag in Gas-Filled Photoelectric Cells, by A. M. Skellett. 10 pages, illustrations. B-1095, The χ^2-Test of Significance, by Thornton C. Fry. 13 pages, illustrations. B-1097, Electron Microscope Studies of Thoriated Tungsten, by Arthur J. Ahearn and Joseph A. Becker. 25 pages, illustrations. B-1098, The Bridge-Stabilized Oscillator, by L. A. Meacham. 17 pages, illustrations. B-1099, Dielectric Constant and Dielectric Loss of Plastics as Related to Composition, by W. A. Yager. 22 pages, illustrations. B-1100, The Exponential Transmission Line, by Chas. R. Burrows. 19 pages, illustrations. B-1103, Devices for Controlling Amplitude Characteristics of Telephonic Signals, by A. C. Norwine. 16 pages, illustrations. B-1106, Amplitude Range Control, by S. B. Wright. 19 pages, illustrations. B-1107, Sound Pictures in Auditory Perspective, by Franklin L. Hunt. 7 pages, tables. Ten pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1938.